DACCA UNIVERSITY EXTENSION LECTURES

MAKERS OF
MODERN CHEMISTRY

BY
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WITH A FOREWORD BY
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There is no delight like that which springs from a discovery ; it is a joy that gladdens the heart.—Scheele.

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PREFACE

These lectures were delivered extempore from short notes and are published almost in the form in which they were given. Lecture IV and "The Story of the Discovery of Oxygen" have been rewritten with considerable additions. Students of chemistry, in this country at any rate, have been found to pay scant attention to the historical development of our science, and these lectures are published at the suggestion of the authorities of the University of Dacca in the hope that their interest in the subject may be roused.

One important fact is often apt to be lost sight of: while some of the fundamental laws of mechanics and physics, as for example, those propounded by Archimedes, Galileo and Newton, have been known from the third century B.C. and onwards, the answer to the question: "What becomes of a candle when it burns"? in other words, the scientific explanation of the phenomenon of combustion was only forthcoming towards the end of the eighteenth century.

It has been shown how a brilliant and unbroken succession of devotees has handed down the torch from one generation to another irrespective of country or nationality. The school of Berzelius, for instance, claims

amongst its most brilliant disciples, Germans like Mitscherlich, the Roses and Wöhler. Liebig, again, sat at the feet of Gay-Lussac; while Piria the Italian chemist was a disciple of Dumas. Piria in his turn was a teacher of his great countryman, Cannizzaro; Playfair and Williamson were pupils of Liebig at the laboratory of Giessen. Frankland and Roscoe had their inspiration from Bunsen at the laboratories of Marburg and Heidelberg respectively.

The original discoverers themselves have often been allowed to tell their own tales so as to give vividness to the delineations. The nomenclature, such as we are accustomed to, owes its origin to Lavoisier and his colleagues, and hence to use such terms as potassium nitrate, nitric or sulphuric or hydrochloric acid in treating of the chemical literature of the pre-Lavoisierian days would render one guilty of anachronism.

As the audience consisted of junior and advanced students as also teachers, I had to take special care that the lectures might not be pitched in too high a key.

My special thanks are due to Dr. Hartog, Vice-Chancellor, Dacca University, and to my pupil and friend Prof. J. C. Ghosh at whose request these lectures were delivered and who have taken a warm interest in their publication. Dr. Hartog has laid me under further

obligation by contributing the foreword. To my pupil and colleague Prof. P. C. Mitter I am indebted for the materials used in Lecture IV.

I wish also to express my indebtedness to Messrs. A. N. Kappanna, M.Sc. and Paresh Chandra Banerjee, M.Sc., lecturers, Dacca University, for their trouble in taking down notes of these lectures. Mr. P. K. Bose, M.Sc., Sir T. N. Palit Research Scholar, College of Science, has rendered me material assistance in seeing the work through the press and my thanks are due to him.

P. C. RÂY.

COLLEGE OF SCIENCE,
October, 1925.

FOREWORD

Sir Prafulla Chandra Rây has asked me to write a Foreword to these lectures of which the first five were given to a large, appreciative, and steadily increasing audience in the University of Dacca. But of all men, Sir Prafulla stands least in need of introduction to the Indian public. With his long, accurate and patient researches in both organic and inorganic chemistry, his pioneering work on the *History of Hindu Chemistry*, his creation of a school of chemistry, in which he has given living inspiration to a whole host of younger men, his origination of the Indian Chemical Society, and above all, that remarkable personality, at once genial and ascetic, full both of reflection and action, alive to knowledge in the most varied fields of human thought, profoundly sensitive to human misfortune, and enthusiastic for social progress, it would be strange indeed if so remarkable a figure did not appeal strongly to the imagination of intellectual India.

These lectures are not intended as a systematic presentment of that vast subject, the History of Chemistry, but to throw a vivid light on some of the great actors in that history and their achievements. Delivered with subtle and genial emphasis, they delighted and

stimulated the audience to which they were addressed. I believe that in the written form they will carry not a little of their original influence to a wider circle.

P. J. HARTOG.

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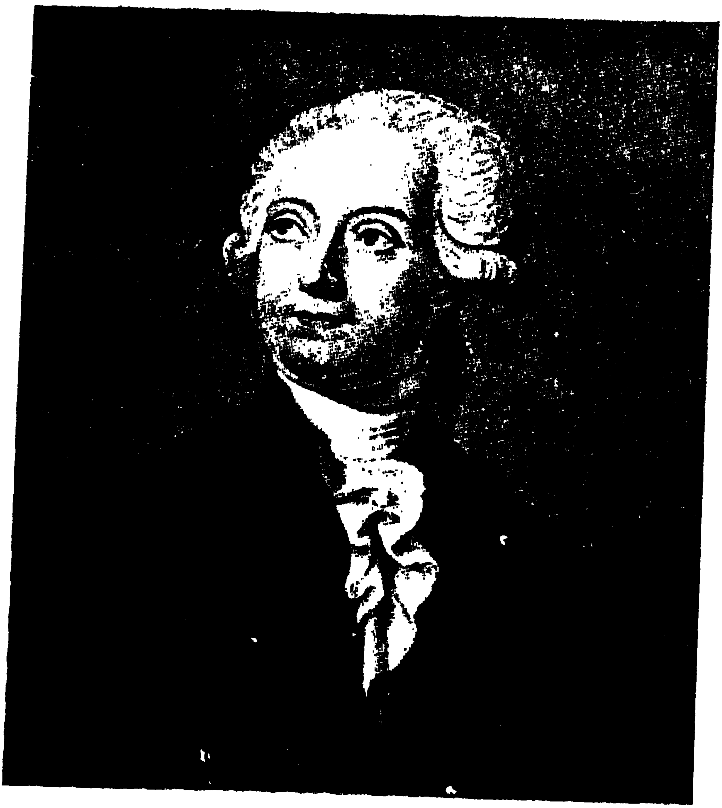

Lavoisier

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Haridbaran Mukerji
College Row Calcutta

MAKERS OF MODERN CHEMISTRY

LECTURE I

Introduction—Obligations to our intellectual ancestors —Jean Rey's work on calcination of metals—Stahl and the basis of Phlogiston Theory—Mayow's work on combustion and respiration—Pet theories and their effect on the progress of science—"Father of Pneumatic Chemistry"— Hooke's explanation of the phenomenon of combustion.

It is so kind of your Vice-Chancellor,— I might say *our* Vice-Chancellor, for I am proud of being a life-member of the Dacca University Court,—to have introduced me thus. I should say at the very outset that I feel rather nervous, for, Dr. Hartog is himself a very keen student of History of Chemistry. I feel I have to face a severe ordeal in having to speak here with him in the presidential chair. There is a saying in Bengal that the great epic Rámáyana cannot be condensed in one breath. Similarly to condense the origin and development of chemistry in six lectures is a difficult task.

Now, students of chemistry are apt to

forget how much they owe to their intellectual ancestors. There is a difference between a man of wealth and a man of science. Both are rich no doubt. The man of wealth bequeathes his treasures to his children or to those who are his next of kin, unless he be a person like Andrew Carnegie, or, coming nearer to our own country, philanthropists like Premchand Roychand or Taraknath Palit or Rash Behari Ghosh, who gave away almost everything they had for the advancement of learning and for the progress of science. But the man of science bequeathes his achievements, not to one particular person, but to all generations that come after him and to the world at large. Everyman can partake of what a Newton, a Faraday, a Berzelius, a Priestley or a Lavoisier has left behind. In a general sense a man of science is the common property of mankind at large; he transcends all arbitrary jurisdictions and narrow political boundaries of time and place. We have, therefore, to remember how much we owe to the pioneers of science, being partners and co-sharers of their legacy. Just as the Americans celebrate the day on which they declared independence (the 4th of July), just as the Swiss take pride in remembering the exploits of William Tell, so should it be our proud privilege to pause awhile now and then and pay reverent homage to the

memories of the founders of modern chemistry.

Talking about the claims of chemists, I often feel that adequate justice has not been done to some of the predecessors of our science, of whom I am going to speak. Ordinarily, Priestley, Lavoisier and Scheele are bracketed together, not unreasonably though, as simultaneous and independent discoverers of oxygen. There is a saying that there is nothing new under the sun. Long before these men were born, other men in other countries had suspected that the air had something to do as regards the phenomenon of burning. Among these Jean Rey comes first and foremost. His memoir on "The Increase of Weight of Tin and Lead on Calcination" was published in 1630, but it was not appreciated at the time and was almost forgotten after him. John Mayow also in a treatise published at Oxford in 1674 clearly explains the part which the "nitro-aerial spirit" of the air plays in combustion. He thus anticipated Priestley almost by a century and half. In Dacca which is a centre of Ayurvedic learning, you have seen the manufacture of *Bhasmas*. *Dhatu Bhasma* is simply and literally an incinerated product of the metal.

I am first of all going to speak to you on the phlogiston theory. Stahl (1660-1734),

following in the footsteps of Becher, is regarded as the father of the phlogistic theory. A metal when calcined in air produces its calx, *i.e.*, its ash, the phlogiston escaping, thus:

Metal—Phlogiston = Calx.

This idea was evidently suggested by burning wood to ashes. Since in this country we generally use wood as fuel, we all know that the weight of the wood is much greater than that of the ashes obtained from it. It was but natural to conclude that the calx was less in weight than the metal because its phlogiston had escaped during burning. You might take a heavy metallic piece of zinc and convert it into oxide. You know its oxide is obtained in such a fine form that you can blow the powder away very easily. This was regarded as showing that the oxide weighed less than the metal. *Apparently*, it had become lighter. Stahl based his phlogistic theory on some such erroneous idea. Conversely, when phlogiston was restored to the calx the latter again became metal or the *killed* metal was *revived*. Let me further give you an exposition of the phlogistic doctrine in the lucid words of Thorpe: A piece of wood burns; a piece of stone does not. Why is this? "Because," answers Stahl, "the wood contains a peculiar principle—the principle of inflammability: the stone does not. Coal, charcoal, wax, oil, phosphorus, sulphur—in

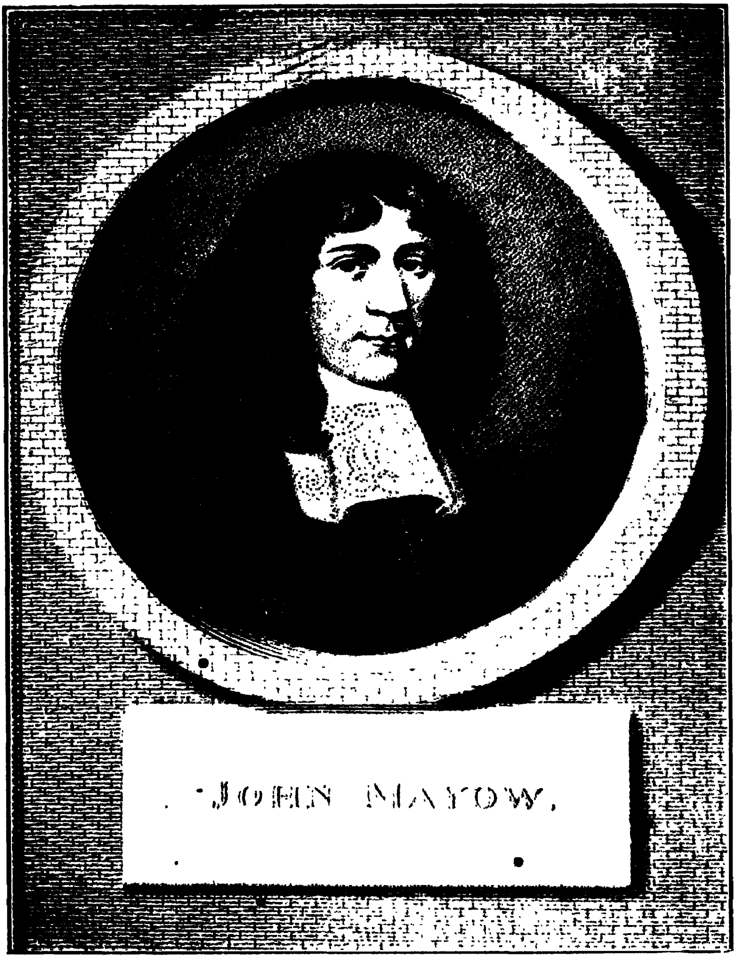
short, all combustible bodies,—contain this principle in common: to this principle (which indeed, I regard as a material substance) I give the name of *Phlogiston.* I regard all combustible bodies, therefore, as compounds, and one of their constituents is this phlogiston: the differences which we observe in combustible substances depend partly upon the nature of the other constituents. When a body burns it parts with its phlogiston; and all the phenomena of combustion—the heat, the light and the flame—are due to the violent expulsion of that substance."

It is interesting to note, as I told you a short while ago, that a century before the formulation of this theory a French medical man and chemist had obtained results which went directly against it. Jean Rey "placed two pounds six ounces of fine English tin in an iron vessel and heated it strongly on an open furnace for the space of six hours with continual agitation and without adding anything to it, he recovered two pounds thirteen ounces of a white calx." We can, therefore, say that even before Mayow or Lavoisier, it was known that metals when heated in air increased in weight, although Rey did not hit upon the exact cause. In those days, just after Renaissance in Europe, great classical scholars had spread the metaphysical ideas of Aristotle and much philosophic value was not

attached to the observations and experiments of Jean Rey, whose work has now been published in the form of a pamphlet in the series, "Alembic Club Reprints," and I am glad to find that it is edited by my old friend and fellow-student "J. W."—James (now Sir James) Walker.

John Mayow (1643-79) died unfortunately when he was only 36. He was an Oxford man and says, "Combustion is due to that portion in the air which occurs in saltpetre, which is also helpful for respiration." John Mayow's work had to be unearthed from oblivion very recently by my own revered teachers, Alexander Crum Brown and Leonard Dobbin who say, "After the great revolution in chemical theory which followed the discovery of oxygen, Mayow's book was discovered in old libraries, where it had remained disregarded for a hundred years; and those who discovered it were astonished to see that the new chemistry which was rapidly conquering the scientific world was to be found in this old book." Your Vice-Chancellor also contributed a monograph on John Mayow in 1894 to the *Dictionary of National Biography*.

One hundred years before oxygen was formally discovered and christened, Mayow had demonstrated and specified its importance. He argued: if we could burn a thing in ordinary air why do not do it in saltpetre,

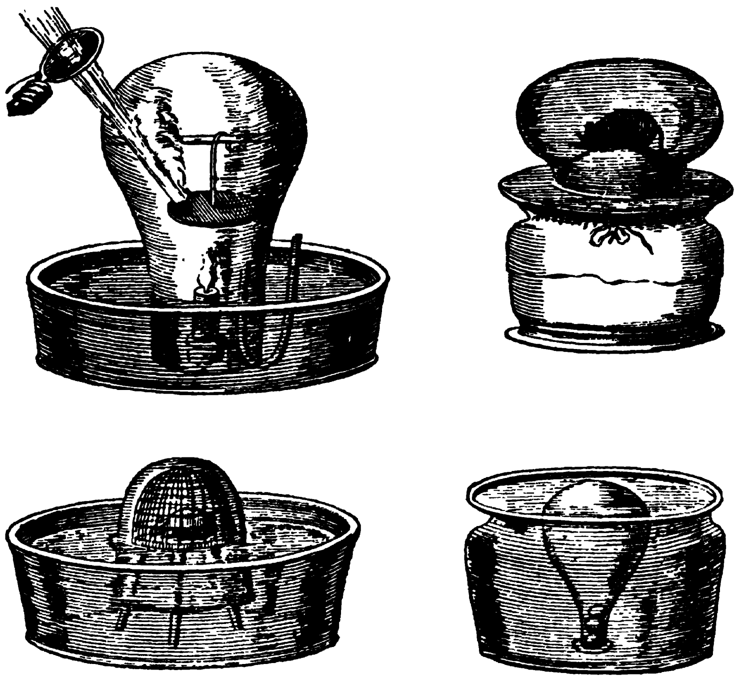

JOHN MAYOW.

which contains that particular principle? An ordinary lecture experiment is shown now-a-days based upon the same principle. Crystals of chlorate of potash and a few pieces of phosphorus of the size of a pea are deposited at the bottom of a tall cylinder, which is then placed in a slanting position and water added so as to nearly fill the cylinder. A few c.c.'s of strong sulphuric acid are then cautiously poured over the mixture by means of a thistle funnel reaching to its surface. The phosphorus will then catch fire and burn under water.

Mayow performed a similar experiment by burning a mixture of sulphur and nitre under water. Mayow's work, however, as I said, was consigned to oblivion. People tried to explain the phenomenon of combustion in the light of the phlogiston theory. A good many theories come into existence and after serving a certain term fall into disuse. In the history of science you will come across many instances of this type. Newton first of all put forth his corpuscular or emission theory of light and this held sway for nearly a century and a half and none dared to utter a word against it, because of the great name of its propounder, in spite of the fact that the Dutch physicist Huygens, a contemporary of Newton, offered a more satisfactory explanation based upon the vibratory motion of

the medium. Consequently, when Young advanced or rather revived the undulatory theory, almost trembling with fear, and offered a clearer and more lucid exposition of the principle of interference of light he was coolly received. Lord Brougham in the *Edinburgh Review* heaped ridicule mixed with invective upon poor Young for his daring and effrontery in calling in question the authority of Newton. In the same way the phlogiston theory had its day. This was of course due to what I might call the tyranny of preconceived notions. Throughout my career at the Presidency College, in my chemistry lectures, I used to mix up social customs with chemistry and talk on the orthodox habits of the Hindus. Phlogistic theory could no more be shaken off than orthodox customs, *e.g.*, untouchability.

Priestley has been called the Father of Pneumatic Chemistry. In his lifetime notions borrowed from the old Greek philosophers prevailed. Everything solid was considered as earth, everything liquid as water, and everything gaseous as air. He popularised the method of collecting gases over water and mercury. In those days of tardy locomotion, scientific workers had very little opportunity of being in touch with the work of people in other countries, and Scheele the great Swedish chemist, who will claim our attention in the



Mayow's Apparatus

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next lecture, had no knowledge of what Priestley was doing in England. John Mayow, however, more properly deserves the title of "Father of Pneumatic Chemistry." Prof. Donnan points out that John Mayow had even a vague idea of the partial pressure of gases. It reflects great credit on him that though a medical man he took pains to carry out experiments on his own account and recorded and anticipated many important chemical and physiological phenomena relating to combustion and respiration ; for instance, Mayow not only correctly anticipated the real cause of combustion of bodies in air but also understood the distinction between arterial and venous blood.

When a Hindu dies, he is said to have attained *panchatwa*, *i.e.*, the condition of the original fivefold state—the idea being that the body returns to and gets converted into the five ingredients of which the habitable earth is composed, namely earth, air, fire, water and ether—earth mixing with earth, fire with fire and so on. A French historian of chemistry, Hoefer, referring to this Hindu conception, says that herein lies in a nutshell the principle of the indestructibility of matter.

I might give you another reference which points to the recognition of a distinct individual, which was later on called oxygen. Robert Hooke, the discoverer of the famous law in-

physics which goes by his name, in his *Micrographia* (1665) says, "when charcoal is burnt, it is burnt at the expense of something in the air." He also states "that the dissolution of sulphureous bodies is made by a substance inherent, and mixt with the Air, that is like, if not the very same, with that which is fixt in Salt-peter, which by multitudes of experiments that may be made with saltpeter, will, I think, most evidently be demonstrated." Harcourt, therefore, very justly remarks: "In reproducing the theory of the *Micrographia* he (Mayow) took no care to give the original author of it the credit which was his due." This was again before Mayow, Priestley and other alleged discoverers of oxygen tried to explain the phenomenon of combustion.

The History of Chemistry is fascinating and captivating. I have given you to-day a general synopsis of the ideas prevailing in Europe at the time when oxygen was discovered. I have just pointed out to you that the discovery of the same fact is often made simultaneously and independently in many countries. But unless the discovery is systematically applied to the explanation of well-known facts it is apt to be forgotten or lost sight of.

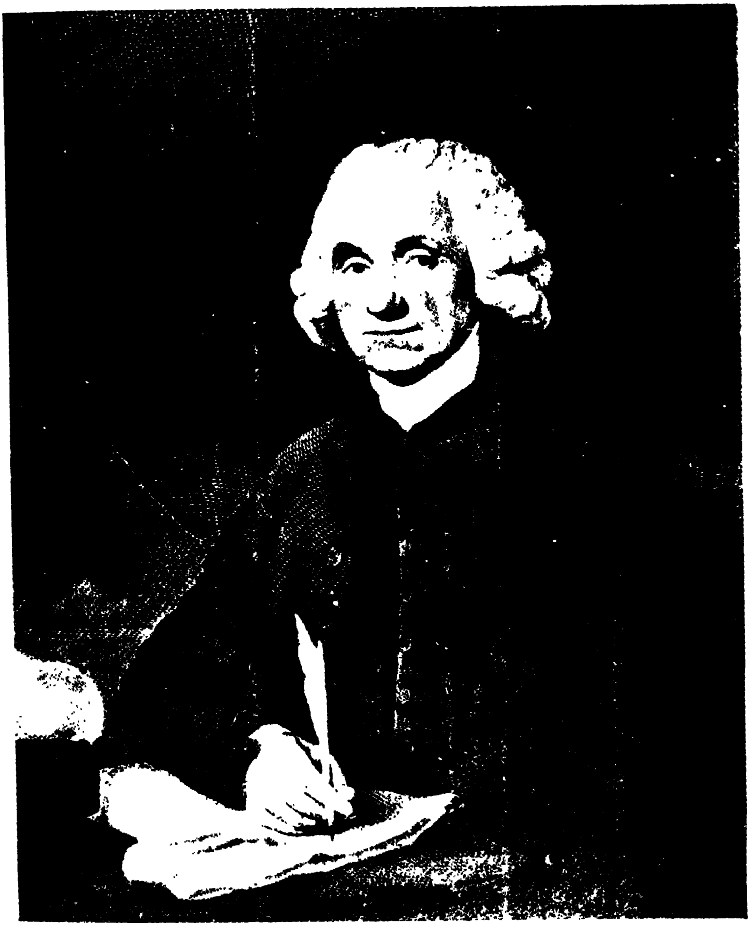
LECTURE II

Joseph Priestley, a versatile genius—Benjamin Franklin—Phlogiston in the free state—Experimental basis of phlogiston theory—Priestley's dephlogisticated air—Priestley in Paris—Lavoisier's classical experiment—Explanation of the phenomenon of combustion—Deathblow to Stahl's doctrine—Other contributions of Priestley—Scheele—His "fire air" and other discoveries—Lavoisier and the French republic—Last days of Priestley.

Three figures stand out prominently in the history of chemistry whose names will for ever be associated with the discovery of oxygen, and the part it plays in the economy of nature, *viz.*, Priestley, Lavoisier and Scheele.

Joseph Priestley (1733-1804) was born of humble parents. Chemistry he pursued more as a hobby and recreation than as a subject of primary interest. His learning was simply encyclopædic,—theology, metaphysics and classical languages mainly occupying his interest. To do full justice to his manifold activities more than one specialist had to be requisitioned. An eminent divine contributes the article on Priestley the theologian, in the *Dictionary of National Biography* and it was left to Dr. Hartog (our Vice-Chancellor) to do justice to Priestley's scientific achievements. The titles of his publications alone cover full five columns of this *Biography* and the number

of papers comes up to the modest figure of one hundred and eight. In the field of theology we might regard him as one of the founders of a refined form of Christianity. I am not going to enter here into any discussion on the dissenting views which he particularly advocated. Suffice it to say that he was one of the leading exponents of that Church which goes by the name of Unitarianism, the religion which corresponds more or less to our Brahmo Samaj. He was noted in his days as a keen controversialist in matters of religion—a redoubtable opponent of the established dogmas. We might rightly regard Priestley as a genius. His interest in scientific investigation showed itself at an early age. While only a boy of eleven, he used to lock up spiders in a bottle to see how long they continued alive. Practically self-taught, when barely twenty he had read the Hebrew Bible twice over. During eight years (1758-66) he kept a school and in order to eke out his scanty income he had recourse to private tuition. The drudgery of teaching occupied him from seven in the morning till seven at night. Happily, however, in 1772 he found a patron in the Earl of Shelburne, who appreciated his merits and took him into his service as his librarian and literary companion. The Earl was a cultured man and in return for the enjoyment he derived from the company of



Priestley

Priestley, he placed him above his common wants. He now found ample opportunities to pursue his favourite studies. Fortunately for us Priestley became a chemist by accident as we shall see presently. I might here add (to compare great things with small) that it was also by an accident that I happened to become a chemist. By nature my inclinations were more towards literature and history. That is, however, a personal matter and is neither here nor there.

About the year 1766 Priestley made the acquaintance of Benjamin Franklin—an acquaintance which ripened into warm and abiding friendship. I may be permitted to make a slight digression here. The more I think of Benjamin Franklin, the more I learn to admire him. Along with Washington, Franklin might also be regarded as the father of American Independence. In the battle for shaking off the bondage of Britain, Franklin took up the diplomatic part of the work. While in England as a representative of America, he tried his best to bring round the English ministers to an amicable settlement. Had they agreed, perhaps history would have taken a different course both for England and America. When he found that his attempts to persuade the English ministry to grant concessions were futile, Franklin went to Paris and there ensured the sympathetic support of the

French. France and England were not on the best of terms with each other after the British conquest of Canada, and Benjamin invoked the assistance of the French at the most opportune moment when they were all anxious and on the look out for an opportunity to wreak their vengeance on the English; and we all know what happened later. Franklin began his life as a compositor, then he became a printer and later on when his financial position improved, he began to carry on experiments just like Priestley during his spare moments. While he was flying a kite on a rainy day, as everyone knows, he discovered electricity in the clouds, and proved, to quote his own words, "the sameness of lightning with electricity" and we owe the lightning conductor to him. When Franklin came to England the third time in 1764, he had an established reputation as a man of science. The learned societies vied with one another in welcoming and showering honours on him. Franklin induced Priestley to write a History of Electricity, which on publication was attended with great success.

By a curious accident Priestley's house in Leeds was situated very near a brewery where he interested himself a great deal in the experiments on the gas produced during fermentation, the 'fixed air' of Black about which he had read previously. But Priestley was never

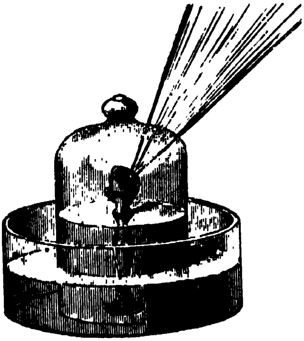


Fig. 1

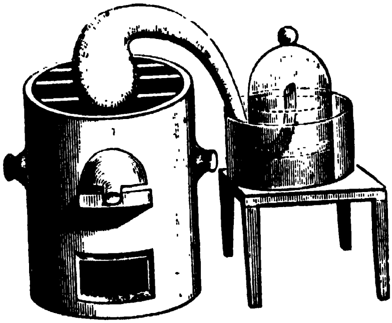


Fig. 2

Fig. 3

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constant in anything. James Watt called his method "random haphazarding." He was like a bee sipping honey from flower to flower. All the same he perceived natural phenomena almost intuitively. One of his earliest experiments was suggested by the memoir of Cavendish on "Inflammable Air". Cavendish was led to suppose that inflammable air was phlogiston in the free state. In order to test this supposition Priestley placed some minium in a crucible within a tall cylinder filled with inflammable air and inverted over water. He then began to heat the minium by means of a burning lens (Fig. 1). "As soon as the minium was dry, by means of the heat thrown upon it I observed that it became black, and then ran in the form of perfect lead; at the same time that the air diminished at a great rate, the water ascending within the receiver."* He concludes "that phlogiston is the same thing as inflammable air, and is contained in a combining state in metals, just as fixed air is contained in chalk and other calcareous substances: both being equally capable of being expelled again in the form of air." He could not of course detect the formation of water in the process as he was carrying on his experiment in a jar over water and thus he missed the glory of being the discoverer of the composition of water. Priestley also believed that

* $Pb_3O_4 + 4H_2 = 3Pb + 4H_2O$.

inflammable air came from iron or zinc when these metals were treated with dilute sulphuric acid, and found an additional experimental support for the view that metals contain phlogiston. In 1774, he performed his celebrated classical experiment on the extraction of 'air' from *mercurius calcinatus per se* (*vide* p. 98). The apparatus made use of by him is given in Fig. 3. He found that a candle burnt more brilliantly in this "air" than in ordinary air and that a mouse lived longer and became more lively in it. This emboldened him to breathe this air himself and he found that it was not only harmless but supported respiration much better. It was unfortunate, however, that he could not explain the rôle of oxygen in combustion. He thought that ordinary air must contain some phlogiston and the new 'air,' he obtained, was free from it. He, therefore, called this gas 'dephlogisticated air'. He attributed the superior power of this air in supporting combustion to the fact that it was capable of receiving more phlogiston from burning substances and could therefore maintain a flame for a longer period than ordinary air. The glory of offering the real explanation of the phenomenon of combustion was reserved for the illustrious Frenchman Lavoisier.

Jean Rey, to whom I had occasion to refer yesterday, heated tin in air without adding anything to it and found that it increased in

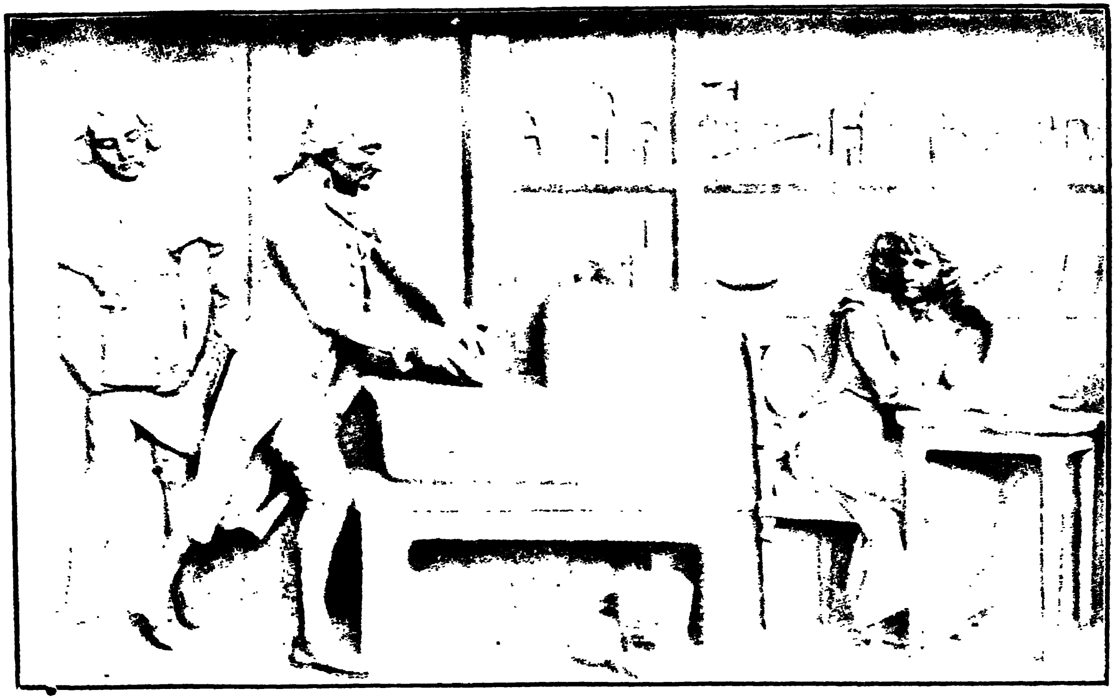
weight. Nearly a century and half later Lavoisier repeated the same experiment and found that tin became coated with a thin film and lost its lustre and also gained in weight, when heated in air. He heated tin also by means of a burning glass (*cf.* Fig. 3) in air enclosed in a bell-jar over water and found that "the volume of air diminished by about a twentieth as a result of the calcination, and that the weight of the metal increased by an amount almost equal to that of the air destroyed or absorbed." He naturally concluded that a portion of the air combined with the metal during its calcination, and that the increase in weight of the calx was due to this cause. According to Priestley and the phlogistians: *Calx = Metal — Phlogiston*, while Lavoisier arrived at the conclusion: *Calx = Metal + Air.*

Priestley in the course of a continental tour went to Paris and naturally he called on Lavoisier, who invited him to dinner. While at the table, Priestley talked about the new air which he had extracted from the calx of mercury. Lavoisier according to certain historians of chemistry maintained silence like a shrewd man and evidently followed the advice of Polonius to his son:

"Give everyman thine ear,
but few thy voice."

Very shortly after, Lavoisier made arrangements for his classical experiment. He took a

weighed quantity of mercury in a retort, its drawn out neck being placed under an inverted bell-jar over mercury (Fig. 2). The retort was heated in a furnace for twelve days and nights and assisted by his worthy wife, he went on observing the changes. Not only did the surface of mercury become tarnished but he found also some red shining scales floating on it, and in proportion as the quantity of these scales increased, the air in the bell-jar diminished and mercury gradually rose up. After a few days there was no further change or diminution in the volume of air; he measured the residual volume of air and compared it with the original and found that nearly one-fifth had disappeared. At this stage the experiment was stopped. He then performed the reverse experiment by heating the red calx of mercury and obtained that very 'air' of Priestley and also noticed globules of mercury deposited on the cooler parts of the vessel. He naturally came to the conclusion that Priestley's new air was evidently taken from the atmospheric air of which it was a component. He then communicated his discovery to the French Academy of Sciences. The charge is sometimes laid at his door that he conveniently forgot to mention his indebtedness to Priestley from whom he had obtained the first information about the matter. Some English historians of chemistry, therefore,



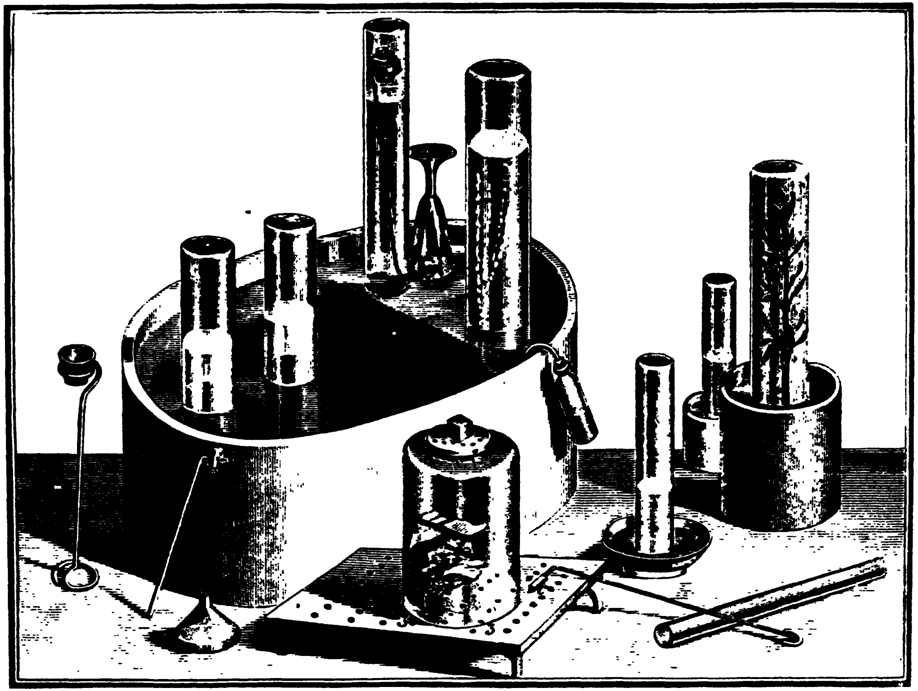
Lavoisier and his Wife

accuse Lavoisier of plagiarism. But this is a different story and it cannot be adequately dealt with here (*vide The Story of the Discovery of Oxygen*, p. 91).

Then Lavoisier began to burn many other things in this 'air' *e.g.*, sulphur, phosphorus, charcoal etc., and explained the phenomenon of combustion. Metals do not lose anything on being heated in contact with air, but in fact gain something from it. He used the balance all along and placed his experiments on a quantitative basis. In fact the 'candle experiment' as described in the elementary textbooks is based upon Lavoisier's classical discovery. He also showed that when a definite quantity of sugar undergoes fermentation the products formed, namely, alcohol and 'fixed air' (carbon dioxide) are exactly equal in weight to that of the sugar taken. Philosophers of the East and West were racking their brains for full 2000 years before this scientific explanation of the phenomenon of burning could be given and thus did Lavoisier open the gates of the glorious empire of chemistry. It is by these experiments and an intelligent and logical interpretation of their results that Lavoisier established the Law of Conservation of Mass, which was gradually accepted by almost all his scientific contemporaries and as though he was dealing a deathblow to the phlogiston theory, he caused a

number of manuscripts purporting to Alchemy to be collected and set fire to by Madame Lavoisier habited as an Egyptian priestess of old, in order to symbolise that out of their ashes should modern chemistry spring forth Sphinx-like. But the obstinate upholders of the phlogiston theory were not to be silenced. They took their stand on another ground. Their argument was that phlogiston possessed levity rather than weight, *i.e.*, it had a negative weight; hence when it was given off by the metal its calx necessarily increased in weight. See how difficult it is to dislodge obdurate upholders of untenable and shaky doctrines!

Chemistry, however, owes a debt immense of endless gratitude to Priestley. He made many other valuable contributions to pneumatic chemistry. By his method of collecting gases by the displacement of mercury he was able to isolate 'alkaline air' (ammonia) and 'marine acid gas' (gaseous hydrochloric acid). To him also we are indebted for the systematic preparation and use of 'nitrous air' in determining the "goodness of air" (*i.e.*, the amount of dephlogisticated air or oxygen). In his earlier experiments Priestley following in the footsteps of Mayow used living mice, as we have seen, for this purpose. He also made the remarkable discovery that plants render 'vitiated air' (*i.e.*, air charged highly with



Priestley's Apparatus.

carbonic acid gas) again fit for respiration or combustion.

The third of the princely triumvirate, who independently discovered oxygen, was the Swedish chemist Carl Wilhelm Scheele (1741-1781). His father was a tradesman. He received his early education at a private academy and was afterwards removed to a public school. His bent of mind towards chemical studies manifested itself even at this period, and his father anxious to gratify his desire got him apprenticed to an apothecary named Bauch in Gothenburg. It was here that he laid the foundation of his future greatness. He studied with unremitting perseverance the works of Lemery, Kunckel and Stahl. Through his own exertions he acquired marvellous manipulative skill. On the expiry of his term he joined other apothecaries at Malmo, Upsala, Stockholm and Köping, and while at this last place he "made more discoveries than all the chemists of his time united together," although his experiments were performed under the most unpropitious circumstances. He improvised his apparatus from broken bottles and glass-tubes and enriched chemistry with original contributions of the highest value though he was often "hampered by poverty and harassed by debt." He heated nitre and the calxes of silver and

gold* and called the gas liberated "fire air," (oxygen) since he found that charcoal burnt more brilliantly in it than in atmospheric air. He collected the gases he prepared in empty bladders just as balloons are filled with hydrogen to-day. He began his work under the most depressing conditions as he had none to back him or appreciate his worth. He also obtained 'fire air' by heating pyrolusite with 'oil of vitriol' and found that it contained another element in combination with it and thus discovered manganese. Among his other discoveries may be mentioned hydrofluoric acid, oxalic acid, citric acid, chlorine and "Scheele's green." Scheele showed that iron rusted in air confined over water and that a candle would not burn in the residual air. He also showed that 'fire air' could be removed from atmospheric air by means of ferrous

* Silver and gold do not yield calxes (*i.e.*, do no directly combine with oxygen even under strong heat). Silver, however, dissolves readily in *aqua fortis* (nitric acid). Gold dissolves only in a mixture of *aqua fortis* and *spirit of salt* (hydrochloric acid) named by the alchemists *aqua regia*. Silver thus came to be known as a *quasi-noble* and gold a *noble metal*. Scheele took a solution of silver nitrate and precipitated it with "alkali of tartar" (potassium carbonate) and thus obtained silver carbonate, which on being heated yielded a mixture of "aerial acid" (carbon dioxide) and "fire-air." The former he removed by milk of lime, leaving only pure fire-air. Chloride of gold similarly treated gave "the same fire-air, except that no aerial acid accompanied it. This is not to be wondered at, because the saturated solution of gold effervesces with the alkali, which does not take place with the solution of silver" (Scheele).

hydroxide, liver of sulphur (polysulphides of potassium), turpentine and various other materials and also phosphorus. Indeed, his method of removing 'fire-air' from ordinary air is the same as that adopted to-day in the lecture experiments for the preparation of nitrogen. We quote below Scheele's own words:

"I placed 9 grains of phosphorus in a thin flask, which was capable of holding 30 ounces of water and closed its mouth very tightly. I then heated, with a burning candle, the part of the flask where the phosphorus lay; the phosphorus began to melt, and immediately afterwards took fire; the flask became filled with a white cloud, which attached itself to the sides like white flowers; this was the dry acid of phosphorus. After the flask had become cold again, I held it, inverted, under water and opened it; scarcely had this been done when the external air pressed water into the flask: this water amounted to 9 ounces."

"When I placed pieces of phosphorus in the same flask and allowed it to stand, closed, for 6 weeks, or until it no longer glowed, I found that $\frac{1}{3}$ of the air had been lost."*

In his days the famous Bergman was the President of the Swedish Academy of Sciences

* Strictly one-fifth of the air is consumed by phosphorus. The mouth of the flask though "closed very tightly" was not absolutely air-tight, hence there was most likely leakage.

and Scheele communicated two of his earliest papers to the Academy, which were referred to Bergman who advised their non-publication. This naturally disheartened the poor apothecary. Bergman, however, appreciating Scheele's subsequent contributions became his fast friend and did everything in his power to encourage him.

We thus see that of the three discoverers of oxygen, only Lavoisier was in affluent circumstances, while the other two had to struggle hard, at least during their early days. Lavoisier had also grown wealthy as a farmer-general—a system which lent itself to corruption, jobbery and oppression and had thus bad odour attached to it. The right of collecting the indirect taxes, *e.g.*, customs, excise, octroi, taxes on wines, salts, tobacco, etc., was farmed or leased out to a syndicate of financiers in return for a fixed sum payable in advance to the state. The latter in turn were often given a *carte blanche* to extract as much as they could from the consumers—mostly poor peasants. Though Lavoisier was personally honest and spent his fortune lavishly for the advancement of science, he had the misfortune to incur the odium attached to the hated system. When the French Revolution broke out, the wrath of the republicans was directed mainly towards aristocrats and bishops, who enjoyed privileges and oppressed

the peasantry. Therefore, the first thing they did was to get rid of these undesirables. Lavoisier could not escape the vengeance of these furies. He was arrested and sentenced to be guillotined along with twenty seven others. An appeal was made to postpone the execution of the great scientist so that he might commit to writing the results of some of his latest discoveries, but in vain. Coffinhal, who presided over the court, cynically said: "La République n'a pas besoin de savants" (The Republic has no need of savants). Thus ended the tragic career of the immortal Lavoisier who may justly be designated as the Father of Scientific Chemistry. May his soul rest in peace!

In this connexion it is also worth while to remember that his great rival narrowly escaped sharing a similar fate. Priestley and the other leading dissenters of Birmingham, because of their open and avowed sympathy with the revolutionists of France, incurred the wrath of the local clergy and of the populace. An excited and riotous mob vented their fury by attacking and wrecking Priestley's house (1791). He and his family fortunately managed to escape before the rioters arrived. His laboratory and all the instruments and apparatus were smashed to pieces. He fled to London under an assumed name and afterwards decided to go into exile. "His opinions,"

though by no means uncommon at the present day, were so antagonistic to those of his English contemporaries that he was cut by his Fellows of the Royal Society, and he therefore resigned his Fellowship. And this feeling was in no way lessened by the action of the French Government of the time, which made him a Citizen of the Republic, and even chose him as a member of their Legislative Assembly. Arriving in America in 1795, he was well received, and settled at Northumberland, not far from Philadelphia. There he died in 1804." (Ramsay).

LECTURE III

Lavoisier accused of plagiarism—Interest created in the pursuit of natural sciences and specially of chemistry in France—Its effect on the social system—Davy's early life—"Laughing gas"—His achievements—Isolation of potassium.

The phlogiston theory maintained, as has already been pointed out, that something is taken away from instead of being added to the metal when its calx is formed. There was, therefore, much commotion in scientific circles when Lavoisier's work threatened to aim a death-blow at Stahl's doctrine. Although Priestley had performed several fruitful experiments, he could not satisfactorily account for the phenomena he observed. He could never ponder over things deeply. Lavoisier was gifted with a keener philosophical insight and whatever may be said about the priority of the discovery of oxygen, the credit of having laid the foundation stone of the glorious structure of chemistry belongs to him. As I told you in my last lecture, Lavoisier has been accused of plagiarism by some English historians. It is not improbable that the bias of patriotism plays an important part in the formation of such an opinion.* We

* *Cf.* 'Many of the charges which have been brought against Lavoisier's good faith unfortunately turn out upon investigation to be well founded, so that whilst we must greatly admire the

as Indians—as a third party—can afford to judge the question impartially, for, we do not hold a brief either for the English or for the French and can thus adjudicate between the rival claims. Our Vice-Chancellor, who is himself an authority on the subject, will, I trust, throw some light upon it when the course of lectures is ended.

The interest created in the pursuit of natural sciences and specially of chemistry by its learned exponents and the social revolution it effected is thus graphically described by Buckle in a passage of surpassing beauty and eloquence:

"In France, before the Revolution, the people, though always very social, were also very exclusive. The upper classes, protected by an imaginary superiority, looked with scorn upon those whose birth or titles were unequal to their own. The class immediately below them copied and communicated their example, and every order in society endeavoured to find some fanciful distinction which should guard them from the contamination of their inferiors. The only three real sources of superiority,—the superiority of morals, of intellect, and of knowledge,—were entirely overlooked in this absurd scheme; and men became accustomed to pride themselves not on any essential difference, but on those inferior matters, which, with extremely few exception, are the result of accident, and therefore no test of merit.

The first great blow to this state of things, was the unprecedented impulse given to the cultivation of physical

clear sight of the philosopher, we cannot feel the same degree of respect for the moral character of the man'—Roscoe and Schorlemmer.

science. Those vast discoveries which were being made, not only stimulated the intellect of thinking men, but even roused the curiosity of the more thoughtless parts of society. The lectures of chemists, of geologists, of mineralogists, and of physiologists, were attended by those who came to wonder, as well as by those who came to learn. In Paris, the scientific assemblages were crowded to overflowing. The halls and amphitheatres in which the great truths of nature were expounded, were no longer able to hold their audience, and in several instances it was found necessary to enlarge them. The sittings of the Academy, instead of being confined to a few solitary scholars, were frequented by every one whose rank or influence enabled them to secure a place. Even women of fashion, forgetting their usual frivolity, hastened to hear discussions on the composition of a mineral, on the discovery of a new salt, on the structure of plants, on the organization of animals, on the properties of the electric fluid. A sudden craving after knowledge seemed to have smitten every rank. The largest and the most difficult inquiries found favour in the eyes of those whose fathers had hardly heard the names of the sciences to which they belonged. The brilliant imagination of Buffon made geology suddenly popular; the same thing was effected for chemistry by the eloquence of Fourcroy, and for electricity by Nollet; while the admirable expositions of Lalande caused astronomy itself to be generally cultivated. In a word, it is enough to say, that during the thirty years preceding the Revolution, the spread of physical science was so rapid, that in its favour the old classical studies were despised; it was considered the essential basis of a good education, and some slight acquaintance with it was deemed necessary for every class, except those who were obliged to support themselves by their daily labour. The results produced by this remarkable change are very curious, and from their energy and rapidity were very decisive. As long as the different

classes confined themselves to pursuits peculiar to their own sphere, they were encouraged to preserve their separate habits ; and the subordination, or, as it were, the hierarchy, of society was easily maintained. But when the members of the various orders met in the same place with the same object, they became knit together by a new sympathy. The highest and most durable of all pleasures, the pleasure caused by the perception of fresh truths, was now a great link, which banded together those social elements that were formerly wrapped up in the pride of their own isolation. Besides this, there was also given to them not only a new pursuit, but also a new standard of merit. In the amphitheatre and the lecture-room, the first object of attention is the professor and the lecturer. The division is between those who teach and those who learn. The subordination of ranks makes way for the subordination of knowledge. The petty and conventional distinctions of fashionable life are succeeded by those large and genuine distinctions, by which alone man is really separated from man. The progress of the intellect supplies a new object of veneration ; the old worship of rank is rudely disturbed, and its superstitious devotees are taught to bow the knee before what to them is the shrine of a strange god. The hall of science is the temple of democracy. Those, who come to learn, confess their own ignorance, abrogate in some degree their own superiority and begin to perceive that the greatness of men has no connection with the splendour of their titles, or the dignity of their birth."

I have read out to you the above somewhat lengthy extract in view of its particular applicability to our own social hierarchy. In India even at the present moment the artificial barrier between the classes and the masses—in short, the pernicious caste system based upon arrogant untenable pretensions is working

Davy

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infinite mischief and is the main stumbling-block in the path of nation-building.

Throughout Europe chemistry, as now placed on a scientific basis by the labours of Lavoisier and seconded by his school, composed of de Morveau, Fourcroy and Berthollet, began naturally to be known as the *French Science* long before Wurtz characterised it as such (p. 104).

We next pass on to another chemist who flourished shortly after Lavoisier. This is Davy (1778-1829). Davy, again, like most of the chemists who flourished and became famous towards the close of the 18th and the beginning of the 19th century, came of a poor family. He was born in Cornwall. An indigent lad, he had absolutely no opportunities of a systematic training or of getting any lessons from anybody. His father died when he was quite young leaving him to the care of his widowed mother. To keep his body and soul together and to maintain his younger brothers, Davy had to take to work and he secured apprenticeship to an apothecary and surgeon at Penzance. Davy was really a poet and became a chemist purely by accident. His poetical genius was of such a high order that later on he counted among his friends, Coleridge, Southey and others. In fact, Southey submitted his poem *The Thalaba* to Davy for revision before he could make up his mind to

publish it, such was the esteem in which he was held even by poets of eminence. But all this poetic fervour had to be suppressed. He "marked out for himself a course of study and self-tuition quite unparalleled in the annals of biography." You will find that almost all the early makers of scientific chemistry have submitted themselves to such self-tuition and undergone similar vissicitudes of life before they could lift their heads up. Then "from reading and speculation he soon passed to experiment. But at this time (1797) he had never seen a chemical operation performed and had little or no acquaintance with even as much as the forms of chemical apparatus. Phials, wine-glasses, tea-cups and tobacco-pipes, with an occasional earthen crucible, were all the paraphernalia he could command; the common mineral acids, the alkalis, and a few drugs from the surgery constituted his stock of chemicals." While he was experimenting with such wonderful apparatus, by a remarkable accident a copy of Kerr's translation of Lavoisier's *Chemistry* fell into his hands. By this time he had also read about many of Priestley's experiments and repeated most of them. Sometimes in the history of science it so happens as though Providence plays a prominent part in the affairs of men. Dr. Beddoes after his retirement from professorship at Oxford could not end his days in

indolence but being full of whims a novel idea caught hold of him. Patients are usually treated by liquid and solid drugs. Beddoes' idea was that gases also might be used as drugs. Possessed with this idea he established a Pneumatic Institution at Clifton where patients could be cured by making them inhale gaseous drugs—not a very safe thing to do—rather full of danger. You know the discoverer of arseniuretted hydrogen—Gehlen—happened to inhale a single bubble of the gas and did not survive to tell the tale of his experiences. Therefore, the use of gases as drugs is liable to be attended with risks. But Dr. Beddoes was of a bent of mind bristling with fantastic ideas. His scientific aberrations, however, led to the discovery of Davy whose skill in performing chemical experiments was locally known. He at once appointed him his chief assistant. It was here that young Davy prepared the nitrous oxide of Priestley and discovered its intoxicating properties. Once he inhaled this gas and felt a strange sensation and began to dance about the laboratory as a madman. This was a great discovery. His dancing at once drew the attention of his neighbours. New things have a peculiar capacity for catching public fancy—you see to-day so many 'pathies',—electropathy, homœopathy, allopathy, hydropathy and telepathy.

Gradually 'laughing gas' came to be known all over the land and Davy at once shot like a meteor into fame. Repeated invitations came to him from certain influential quarters in London and when he went to the great metropolis it became quite the rage to prepare and demonstrate the physiological effects of laughing gas in drawing rooms before fashionable societies. By this time the Royal Institution had been brought into existence chiefly through the exertions of Count Rumford and Davy was appointed a demonstrator in the Institution under Professor Garnett. Here again he used to exhibit the effects of 'laughing gas' to all the fashionable people who gathered there. He attracted so much notice that within a short time, when he was barely twenty-two, he was appointed to succeed Dr. Garnett as lecturer in chemistry at the Royal Institution. Count Rumford was at first not much in favour of appointing so young a man to such an important post and to test his mettle, before his appointment, he asked Davy to deliver a lecture on a particular subject in a small room. Davy acquitted himself so well that without any hesitation Rumford confirmed the choice. You perhaps know that Pitt the Elder (Earl of Chatham) was similarly taxed in Parliament by Horace Walpole with 'the atrocious crime' of youth! But many famous chemists did remarkable things while

Royal Institution—Demonstration on Laughing Gas.

young. Van't Hoff was only twenty-two when he put forward the theory of the asymmetric carbon atom. Pasteur, Arrhenius and many others accomplished great things at an early age. Davy as I have said was of a poetic nature and his lectures at the Royal Institution were so full of rhetoric and poetry that he attracted larger audiences. He became a favourite in society—in fact began to be lionised and could not keep his head cool. Burns the Ayrshire ploughman-poet became very suddenly famous like Davy and was drawn into the vortex of fashionable societies in Edinburgh, but at the zenith of his glory he kept his head cool and underwent the ordeal like a real man. It was otherwise with Davy. He now began to court and frequent gay and aristocratic societies and was captivated by the charms of a rich widow whom he married. It was unfortunately not quite a happy union. John, the brother and biographer of Sir Humphry Davy, says: "Better had it been for my brother and his wife, had they never met each other."

While almost every country in Europe was contributing its quota to the development of science, Italy was not idle and behindhand. Galvani and Volta had discovered the properties of the so-called electric fluid. Nicholson and Carlisle had already applied this voltaic current to the electrolysis

of water (1800) and separated its constituents, hydrogen and oxygen. Davy at once caught the idea of making use of this current in his experiments. Since the time of Lavoisier some new elements had been discovered, but caustic potash and caustic soda were still regarded as elements as attempts to break them into simpler bodies had failed, and nothing had hitherto been obtained out of potash or soda other than itself. Lavoisier had, indeed, shrewdly guessed that caustic potash was of the nature of a calx (oxide) of a metal as, on treatment with an acid, it was neutralised and gave rise to a salt without evolution of hydrogen. Indeed, in 1789 he regarded the alkalis as "evidently compounds, although we are still ignorant of the nature of the principles which enter into their composition." Davy took some caustic potash in a silver dish, heated it to fusion and then introduced the two poles of a battery into this molten mass. He had not the shadow of an idea as to what would happen. To his infinite surprise, he found that silver-like white globules collected at one of the poles and began to catch fire. He was so much affected and overpowered with feelings that he actually danced about the room delirious with excitement. His cousin Edmund relates: "When Humphry saw the silver globules which caught fire his joy knew no bounds and he began to

dance and it was sometime before he could control himself to continue his experiments." Newton, on the eve of his completing the calculations from his Law of Inverse Squares, found that the numerous observations made by Kepler went to establish his theoretical deductions. He grew so nervous and restless that he could not proceed further and a friend of his had to finish the calculations. He was conscious that he was on the threshold of an epochmaking discovery. Such is the ecstasy that a scientific worker feels on the occasion of making great discoveries.

Davy said he could do so much because he was not overtaught. Moreover, he had often to devise his own methods out of crude, unpromising materials. Sir William Thomson (Lord Kelvin) once complained that the luxuriously fitted laboratories, though necessary and useful, were often a hindrance in the way of training a student to fall back on his own resources. Roscoe, in narrating his experiences at Bunsen's laboratory at Heidelberg, similarly complained of the convenience that modern laboratories were providing; they have a tendency to take away the initiative of the young learner as he finds everything he requires ready at hand. The laboratory, to quote Roscoe, "was a quaint one; it had been an old monastery. . . . . . We used Berzelius' spirit-lamps, drew our water from

the pump, and threw down our useless precipitates on the tombstones of the old monks under our feet; all our combustions were of course made with charcoal." In short, there is considerable force in Victor Meyer's observation: "The best work has often been done in the worst laboratories."

LECTURE IV

Elementary nature of chlorine—Paracelsus and his work—Metallic drugs—Basil Valentine—Robert Boyle—*The Sceptical Chymist*—Lives and contributions of de Morveau, Berthollet and Fourcroy—The new chemical nomenclature—Its effect on the progress of chemistry—Vauquelin—Gay-Lussac—Chevreul—Mitscherlich—Dumas—Wöhler and Liebig—Berzelius—Bunsen—Law of Isomorphism—Theory of substitution—Laurent and Gerhardt—Pasteur and his discovery—Epochs in the lives of great men of science.

I was speaking to you the other day about Davy—how a poor lad, born in an obscure village in Cornwall, became one of the most famous men of his day by his remarkable discoveries, of which the isolation of potassium by the electrolysis of fused caustic potash was the most striking. Scheele before Davy had no doubt discovered chlorine by the oxidation of what was in those days known as 'muriatic acid.' Being under the sway of the phlogiston theory, however, he could not detect the elementary nature of chlorine and it was given to Davy to actually demonstrate that the oxymuriatic acid of Scheele had no oxygen in it but that it was an elementary form of matter and he named it chlorine from the Greek word, *chloros* meaning yellowish-green. The accepted view until Davy took up the subject in 1810 may thus be summarised in Berthollet's

own words: Scheele "regards manganese (*i.e.*, the dioxide) as a substance very avid of phlogiston, and believes that it removes this principle from the marine acid, which thereby acquires the properties characterising the gas of dephlogisticated marine acid and that this gas acts upon substances which contain phlogiston by removing this principle from them." Gay-Lussac and Thenard proved by a series of experiments that oxygen could be obtained from oxymuriatic acid; they could not thoroughly dry it and, therefore, when the gas was exposed to light, they naturally obtained muriatic acid and oxygen.* Davy and his brother John, however, proved that if the gas be absolutely dry it does not liberate oxygen when exposed to light and muriatic acid when heated in contact with tin or zinc disengages hydrogen equal to half the volume of the gas, 'giving muriates.'

In a running survey like this it is difficult to follow every precursor of our science with logical sequence. I shall, therefore, make a slight digression and only tell you to what extent we are indebted to two of these. First and foremost stands the name of Paracelsus (1493-1541). Paracelsus has almost been deified by his devotees and followers. They gave him a long and high sounding name. His full

* $Cl_2 + H_2O = 2HCl + O$.

name would be Philippus Aureolus Theophrastus Paracelsus Bombastus. As I have already told you, in those days chemistry was no more than a mere handmaid of medicine. Paracelsus gave a vigorous impetus to the use of metallic preparations as drugs and was thus indirectly instrumental in having them gradually recognised in the pharmacopœias on a large scale. On this account he and his followers took to the performance of chemical operations with assiduity and henceforth chemistry began to assert itself and to be pursued not so much as a handmaid of medicine but as a distinct and independent branch of science. Even to-day at Dacca you will find that Kavirajas (Hindu indigenous physicians) use metallic preparations as recommended in the *Ayurveda* on a very large scale. Ours is a wonderful land. The old and the new thrive here side by side without in any way affecting each other. The *Ayurveda* and the western system of medicine both flourish in our midst.

Paracelsus for the first time said that it would not do to follow blindly the methods of Hippocrates, Galen, Avicenna and Rhases without rhyme or reason. He himself broke away from the established traditions and to awaken the public from their sleep of stupor and ignorance, travelled far and wide preaching and lecturing in his mother-tongue where-

ever he went. (In those days Latin was the language of the learned in the west, just as Sanskrit was in our country not long ago). Paracelsus was a genius and all geniuses are, as a rule, erratic and eccentric. Whenever he lectured he spoke with vehemence about the slavery to which his contemporaries subjected themselves in blindly adoring and sticking to the antiquated methods handed down from the days of the old Greek and Arab physicians. He used to say: "All the accumulations of the medical lore before him were not worth the sole of his boot." He prepared many metallic drugs especially those from antimony and with these effected marvellous cures. The Hindus anticipated Paracelsus by many centuries but he was the first to introduce metallic preparations and especially those of mercury in Europe. Paracelsus was not without opponents. All the representative physicians of France assembled at the Paris Academy of Medicine and openly condemned the use of these innovations. Basil Valentine was another chemist who also introduced some metallic preparations notably of antimony and said that human life was too short to study the preparations of even one metal. This remark is as true to-day as in the days of Basil Valentine.* I myself have devoted a quarter

* Basil Valentine was a monk of southern Germany. He was held in high repute as an alchemist. Several works of later date

of a century to the preparation and study of only two compounds of mercury, namely, mercurous and mercuric nitrites, and am not still tired of them. Carlyle says of a great man: "His face was one wholly in protest and a life-long unsurrendering battle against the world." The medical profession whose method of treatment in vogue he denounced was naturally up against and jealous of Paracelsus. He, therefore, had to wander through many European countries without resting any where, advocating his views.

He had in him one amiable qualification or weakness, whatever you may call it—and in this respect he remarkably resembled the physicist Cavendish—his dread of women. Cavendish was a peculiar man. He would never look at a lady and if he was introduced to any member of the fair sex at the Royal Society soiree, he would feel terribly agitated and run away from her as fast as he could, as if a tiger was on his track.

Paracelsus was the author of numerous works in Latin. He wrote also some of his books in an odd mixture of Latin and German. In one of his books he administered a well deserved rebuke to the physicians of his time; says he, "Chemists do not give themselves up to ease and idleness, strutting about with a

were attributed to him so that they might gain ready acceptance. He is hence often called pseudo-Basil Valentine.

haughty gait, dressed in silk, with rings ostentatiously displayed on their fingers, or silvered poignards fixed on their loins, and sleek gloves on their hands. But they devote themselves diligently to their labours, sweating whole nights and days over fiery furnaces. These do not kill the time with empty talk, but find their delight in their laboratory. They are clad in leathern garments, and wear a girdle to wipe their hands upon. They put their fingers among coals, the lute, and the dung, not into gold rings. Like blacksmiths and coal merchants, they are sooty and dirty, and do not look proudly with sleek countenance. In presence of the sick they do not chatter and vaunt their own medicines. They perceive that the work should glorify the workman, not the workman the work, and that fine words go a very little way towards curing sick folks. Passing by all these vanities, therefore, they rejoice to be occupied at the fire and to learn the steps of alchemical knowledge."

Browning wrote a poem on Paracelsus. You can read it for yourselves and see what moral it has for you. The poet has done him ample justice and given the portrait of a genuine seeker after truth—one inspired with ardent aspiration of wresting the secrets from nature for the benefit of mankind. Such a one

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has to wrestle with his soul and body as in strong agony.

"God helping, God directing everywhere,
So that the earth shall yield her secrets up.
I seemed to long
At once to trample on, yet save mankind,
To make some unexampled sacrifice
In their behalf, to wring some wondrous good
From heaven or earth for them."

The other remarkable character, who flourished a century later, is Robert Boyle (1627-1691), who is best known as the author of *The Sceptical Chymist* and the discoverer of the law which goes by his name. Boyle, Hooke, Mayow, as also Newton were all contemporaries. He for the first time showed the value of performing experiments. In the words of Kopp: "Boyle following the method of Bacon led stress on experimental and inductive methods". Before his time chemistry was alchemical and couched in fantastic, unintelligible jargon. "In *The Sceptical Chymist*, Boyle pleads for lucidity of expression, for the destruction of tyranny of phrases, for clearing the mind of vague theories which rest on no basis of sound, tested, experimental results. 'I have long observed,' he says, 'that those dialectical subtleties, that the schoolmen too often employ about physiological'—we would say physical—'mysteries are wont

much more to declare the wit of him that uses them, than increase the knowledge or remove the doubts of sober lovers of truth. And such captious subtleties do indeed often puzzle and sometimes silence men, but rarely satisfy them.' " Boyle rendered another great service. He defined an "element" for the first time, practically in the same form in which we define it to-day. His remarkable book imparted a vigorous stimulus to the study of chemistry. By his definition of an element he made havoc with existing notions. At every step he advocated disregard of authority and the necessity for making experiments avoiding the *a priori* method then so much in vogue. Buckle says of him: "First to doubt, then to enquire, and then to discover, was his method." Unless you follow this precept you will never be on the track of a discovery.

Among the chemists who continued and carried on the traditions of Priestley, Scheele and Lavoisier may be mentioned in the first instance Morveau, Berthollet, Fourcroy and Vauquelin.

Guyton de Morveau (1737-1815) was brought up as a lawyer and practised at Dijon, his native town, with conspicuous success. But his predilection was for literature and science, notably chemistry. He set up a small laboratory near his office and like Davy subjected himself to a course of self-tuition. After-

wards "he repaired to Paris, to visit the scientific establishments of that metropolis, and to purchase preparations and apparatus which he still wanted to enable him to pursue with effect his favourite study. For this purpose he applied to Beaume, then one of the most conspicuous of the French chemists. Pleased with his ardour, Beaume inquired what courses of chemistry he had attended. "None" was the answer. "How then could you have learned to make experiments, and above all, how could you have acquired the requisite dexterity?" "Practice," replied the young chemist, "has been my master; melted crucibles and broken retorts my tutors." "In that case," said Beaume, "you have not learned, you have invented." In fact, his passion for chemistry so much overmastered him that he gave up his lucrative practice of law in order that he might devote himself exclusively to his favourite subject. He was one of the prominent chemists to rally round Lavoisier and join him along with Fourcroy and Berthollet in drawing up the new chemical nomenclature in 1787.

Claude-Louis Berthollet (1748-1822), who was the most distinguished among the contemporaries of Lavoisier, at a meeting of the Academy of Sciences in 1785 openly declared himself a convert to the anti-phlogistic doctrine. He effected a revolution in the process

of bleaching by the application of chlorine; he also discovered chlorate of potash in the course of his researches on the action of chlorine on alkalis. In the year 1796 after the conquest of Italy by Bonaparte, Berthollet and Monge were appointed commissioners to proceed to that country and select the rare works of art, which were extorted as ransom. The conqueror of Italy at once became an intimate friend of Berthollet and enrolled himself as his pupil for a time to study chemistry. During the Egyptian campaign Berthollet, along with other savants, accompanied Bonaparte and cheerfully shared the dangers and privations with him, and on his return to France set up a private laboratory at Arcueil near Paris. "Having been informed that Berthollet's earnest pursuits of science had led him into expenses which had considerably deranged his fortune, Napoleon sent for him, and said in a tone of affectionate reproach: 'M. Berthollet, I have always one hundred thousand crowns at the service of my friends.' And in fact this sum was immediately presented to him."

In 1803, Berthollet produced his memorable "Essay on Chemical Statics" in which he discusses the affinities of different bases like potash and soda for an acid, and draws up tables of the capacities of saturation of different acids by a base. He also lays the foundation, though in a crude form, of the

modern Law of Mass Action, which was developed in a more scientific form by Guldberg and Waage in 1867. One of the conclusions to which his general conception led him was that fixity of composition is not the rule, but is the exception among chemical compounds—a conclusion which was successfully combated by his countryman, Proust (see p. 74). Berthollet was one of the earliest to point out that sulphuretted hydrogen, although it possesses all the properties which characterise the acids, does not contain oxygen, proving thereby that Lavoisier's oxygen-theory of acids was untenable.

Antoine Francois de Fourcroy (1755-1809) was born of a noble but absolutely indigent family. His passion was for music and poetry; he even composed some plays for the theatre but the precarious fortune at the stage made him seek some profession which would ensure him bread and butter and a friend of his father made it possible for him to study medicine. From the beginning of his studies he applied himself to chemistry with diligence and in 1781 he published his treatise, *Lessons of Natural History and Chemistry*. Most of his researches were carried jointly with Vauquelin. Through the interest of Buffon he succeeded Macquer in the chair of chemistry at the Jardin du Roi. His diction, power of expression, clearness of exposition and magic

of eloquence were simply marvellous. During the delivery of his lectures his audience was kept spell-bound (see p. 29). As we have already seen he also helped in the promulgation of the new nomenclature.

An American chemist, who believes in teaching the history of chemical discoveries, gives the following vivid, life-like picture of the heroes who figured so conspicuously in connexion with the new nomenclature based upon Lavoisier's life-work.

"It was an epoch-making chapter, the product of four minds—of four actors, if so they may be termed . . . . in one of the most interesting periods in the history of the French people.

And these four actors were Guyton de Morveau, Berthollet, de Fourcroy and Lavoisier. From time to time they had gathered in consultation in Lavoisier's laboratory. Fancy pictures them seated about a simple board, surrounded on every side with huge volumes and manuscripts, and, suspended here and there on the walls or scattered on the floor, were great retorts, measuring jars, primitive balances, with a huge mercury trough and various other appurtenances for the investigations which had been continuously conducted there in the establishment of fundamental principles of our science. Guyton de Morveau's countenance still retained its lawyer-like expression, though for some years chemistry had been his mistress, and there was visible no sign of the influences of those pernicious political activities which later dominated his thoughts and deeds. Nearby sat Berthollet, whose smiling eyes and winsome manner bespoke a gentle, noble nature, delighting in good deeds to his fellows, with every evidence of an intelligence which might well give birth to a *Static*

Chemistry or disport itself in the organization of great schools like the Normal and Polytechnique—with a keen scientific interest in the problem under discussion. And then came Fourcroy—strange being—most agreeable at times, then sarcastic and cunning—able to inspire enthusiasm in his pupils, but yet cold, vindictive, vainly egotistical—a man of moods, though mostly captiously critical. In these particular consultations, however, his bold, saturnine face glowed with animation, while his words flowed rich in constructive thought and happy suggestion. Not yet had the latent fires of hate and destruction made their appearance.

And, in friendliest interchange of ideas shone the *spiritual* face of him who had explained oxidation, combustion, and respiration, as well as the profound principle of the indestructibility of matter. That was Lavoisier, the dominant figure in the group of actors; all antiphlogistians. Convinced of the correctness of the function of oxygen in chemical reactions, cognizant of the simplicity it ushered into the prevailing chemical thought and wearied by the burdensome nomenclature which had accumulated through the ages, they regarded it a duty incumbent upon them, to let their light illuminate the darksome expressions which enthralled all chemical literature. And, thus, out of their numerous conferences came the light which promptly shone everywhere. Its welcome rays made our tasks as chemical students lighter and endurable. And to that little group of actors, chemists of all time will be indebted. For that reason I am here, lest you may forget the debt you and I owe Guyton de Morveau, Berthollet, Fourcroy and Lavoisier. They had chafed under the chaotic condition of chemical literature, but discerning a new path they made bold to pursue it, and were

> ranked among the first chymists in Europe—

but not until they maturely studied the

> metaphysic of language, and the conformity of ideas with

words, did they venture to present their general nomenclature.

* * * * *

And now, together, let us inspect the nomenclature of chemistry as it was in the period to which the preceding observations refer. Suppose I should speak the words *potassium sulfate*—just those two words. At once each of you recognizes a familiar body. It is an old friend. Its properties loom up before you. But, if I had said hand me a bit of *sal polychrestum Glaseri*, or *Tartarus vitriolatus*, or *Vitriolum potassae*, or *Sal de duobus*, or *Arcanum duplicatum*, where would you be? And yet these names represented potassium sulfate. They were in number five—a burden to the memory, and in no instance giving the slightest indication as to what was meant. At least we would say so. They were also a burden to those four devoted *first chymists*, for Lavoisier wrote:

> Many of the chymical terms have been introduced by the alchemists: terms which we should not expect to find perfect, knowing how difficult it would be for the authors to convey to the readers a knowledge which they had not themselves; I mean ideas agreeable to truth and accuracy. Moreover their design was not always to speak so as to be understood. They made use of an enigmatical language peculiar to themselves, which in general presented one meaning for the adepts and another meaning for the vulgar, which at the same time contained nothing that was rationally intelligible either for the one or the other.

On proceeding further it will be discovered that a *Death's head* signified a vessel for distilling, and that *Caput mortuum* was the residue left upon distillation.

* * * * *

And when we consider that our four actors were engulfed in the voluminous, ponderous chemical literature of the ages that had intervened since our science was cradled in darkest Egypt, we begin to fathom the Herculean task on which they embarked, in order that light and

scientific accuracy might prevail in the literature of our science. To our minds they are heroes. Our admiration for them becomes boundless. We worship their memories, for it is the only way in which our gratitude can express itself.

Eventually, our four actors completed their labors. Recognizing that these were in a sense revolutionary, yet quite sure that if the results were properly promulgated before intelligent audiences the outcome would be a universal and emphatic approval, they modestly addressed that august assembly—the French Academy—informing those distinguished savants that, with the recognition of the function of oxygen in the chemical world, they were able to classify and arrange matter into a few simple groups; and, further, that there logically followed a simplification in chemical nomenclature.

And then on April 18, 1787, Lavoisier, as first speaker, addressing the Academy, said:

> Not until we had reviewed every part of chymistry, and maturely studied the metaphysic of languages, and the conformity of ideas with words, do we venture to present this general nomenclature.

In a brief sketch, beautiful in its simplicity and diction, the great leader proceeded:

> to remove the impediments retarding the progress of chymistry.

Involuntarily, the thought comes, how grand it would have been to have been present on that sublime occasion!

Having thus elucidated the causes for their labors and the concomitant results, on May 2, 1787, de Morveau addressed the Academy, taking as his task the explanation of

> the principles of the methodical nomenclature;

then commented on the substances approaching nearest to a state of simplicity; on the radical principles of the acids; on metallic substances; on the earths; on the alkalies;

and general reactions of compound bodies. It was a remarkable disquisition as every student will declare upon reading it.

And next followed de Fourcroy, displaying tables of arrangement of the nomenclature. This was no easy problem, for with the tables explicit and detailed explanations were given, to which he added on closing:

> If greater facility in study and more perspicuity in expression result from these innovations as the trials which have been made this year (1787) in the public lectures at the Jardin du Roi and at the Lyceum, give us reason to expect, the reformation which we propose, founded upon the most simple method, must certainly be favourable to the future advancement of the science (chymistry).

This, too, was a remarkable address, delivered before an impartial and impassive judge that

> applauds the efforts made under its inspection to do away errors and prejudices and to extend the dominion of truth; but—slow to pronounce.

Nevertheless, the august body joined in the universal acclaim accorded this brilliant effort and exposition.

Berthollet's portion, in the final presentation, appears to have been that of a general elucidator; one intent upon the whole procedure, here and there emphasising and coordinating the various minor corrections, and refreshing the memories of the auditors upon sections of the work which had been momentarily forgotten.

It was, indeed, an epoch-making chapter which our "four actors" wrote, but rarely do we stop in our onward progress to give it consideration. Our enjoyments, our privileges as a rule hark back to grand, heroic efforts, and not seldom to deepest sacrifices.

In my possession is a remarkable picture bearing the title *The Arrest of Lavoisier*. Yes, only a few years subsequent to those red-letter days in the French Academy, our four actors appeared under other conditions. The awful Revolution and Reign of Terror were approaching. De

Morveau apparently had lost every recollection of his mistress, Chemistry! As a member of the Assembly and Convention, he led in the wildest revolutionary outburst and movements. Berthollet sought kindlier surroundings because averse to these fratricidal premonitions, but Fourcroy was most active. Everywhere his spirit controlled and directed. With him there was but one desire and that the destruction of government and those who in any way befriended it. Hence, Lavoisier soon became to him an object of hate, for the latter labored only for his country's good—not, however, as Fourcroy saw the good; so it was the maddened fury of Fourcroy that occasioned the arrest of Lavoisier, for he was relentless—his object was to crush Lavoisier.

And, there, in the picture stands Lavoisier, majestic in attitude and mien, confronted by a mob which had with violence gained access to his laboratory. The scum of Paris, armed with bayonets, clubs, with the crudest instruments of destruction, howled, sneered, and derided the noble soul, until a pompous leader with a victory cap on his head and a brilliant girdle about his loins, haughtily delivered the contents of the paper of arrest to Lavoisier. It is a picture that rivets attention, depicting as it does a stirring scence—yet horrible as its consequences are recalled. After the arrest, came the trial and condemnation."*

It is but fair to add that Cuvier who pronounced the Eloge of Fourcroy exculpates him from the charge of being a party to the arrest and trial of Lavoisier. Says he: "If in the rigorous researches which we have made we had found the smallest proof of an atrocity so horrible, no human power could have induced

* E. F. Smith in the *Journal of Chemical Education*, July, 1925, pp. 538 *et seq.*

us to sully our mouths with his *Eloge*, or to have pronounced it within the walls of this temple (Academy of Sciences), which ought to be no less sacred to honour than to genius."

Louis Nicolas Vauquelin (1763-1829) was the son of an ordinary peasant. After reading in a village school he came to Rouen at the age of thirteen and got employment with an apothecary. The latter used to give lessons in chemistry. Vauquelin attended the lessons secretly and took notes. When his master came to know of it he snatched away the note-book and took the boy severely to task for neglecting his legitimate menial duty. This induced Vauquelin to leave for Paris with six borrowed francs in his pocket. He was in great distress until he got an appointment under Fourcroy. At first his servant then pupil and co-worker, he became ultimately, Fourcroy's intimate friend. Vauquelin quickly rose to eminence and became professor at Ecole de Mines, later successively at the College de France, Jardin des Plants and the Faculte de Medicine. In his laboratory he took pupils, the most famous among whom were Thenard, Chevreul, Pelletier, and Caventou. Cuvier's estimate of the joint work of Fourcroy and Vauquelin will be read with interest. "In their writings one finds at the same time the comprehensive view of Fourcroy, the desire of attacking every problem, of

knowing everything which was one of his characteristics, and the coolness, and the calm but sustained and always ingenious activity with which Vauquelin helped him in attaining his goal."

Thomson also gives a vivid description of the cordial relation existing between the teacher and the pupil: "In these, and many other similar discoveries, which I think it is unnecessary to notice, we do not know what fell to the share of Fourcroy and what to Vauquelin; but there is one merit at least to which Fourcroy is certainly entitled, and it is no small one: he formed and brought forward Vauquelin, and proved to him, ever after, a most steady and indefatigable friend. This is bestowing no small panegyric on his character; for it would have been impossible to have retained such a friend through all the horrors of the French revolution, if his own qualities had not been such as to merit so steady an attachment."

The quantitative analysis of organic compounds dates from 1810, when Gay-Lussac and Thenard published their paper, "Sur l'analyse végétale." Lavoisier had employed mercuric oxide and potassium chlorate for the combustion of organic substances but this was not generally known at the beginning of the nineteenth century. Gay-Lusaac was trained as an engineer. But he was attracted to

chemistry by Berthollet who employed him as his assistant in the laboratory at Arcueil. Although the results of Gay-Lussac's researches often went against his own theories he valued the worth of his young assistant too much to be sorry for his own. We cannot do better than quote Berthollet's words as reported by Arago: "Young man! your destiny is to make discoveries. In future, you will always be my guest at the table. I wish to be your father in matters of science and I am sure I shall one day be proud of the title." To Gay-Lussac we owe the law of combination of gases by volume.

Gay-Lussac's friend and co-worker was Thenard. Louis Jacques Thenard (1777-1857) was the son of .an ordinary peasant. At the age of seventeen he came to Paris to study medicine. As his means did not permit his joining a laboratory as a student he asked Vauquelin for a place as a laboratory servant. Thenard rose to fame with the discovery of the well-known compound "Thenard's Blue". Hydrogen peroxide was also another of his discoveries. He died at the age of eighty as a peer of France and Chancellor of the University of Paris. Among the poor pupils of Vauquelin at Paris was Michel Eugen Chevreul (1786-1889). He forms practically the connecting link between the founders of organic chemistry and many of

the present generation of chemists as he lived to be more than a centenarian. His researches on the fatty acids are too well-known to require repetition here.

To this brilliant group belongs also Eilhard Mitscherlich (1794-1863), who had an exceedingly romantic career. He began life as a student of oriental languages. He studied philosophy at first at Heidelberg then at Paris and had a mind to proceed to Persia to finish his linguistic studies. In order to carry out his plan, he thought it desirable to study medicine and this aroused his interest in the experimental sciences, notably in chemistry. He was also for a time at the laboratory of Berzelius in Stockholm and learnt from the great master accurate methods of mineral analysis. In 1818 he began his researches on the salts of arsenic and phosphoric acids, which led to the discovery of the Law of Isomorphism. We now turn to another group of younger chemists—Dumas, Liebig and Wöhler.

Jean Baptiste André Dumas (1800-84) was at first an apothecary's pupil and then an apothecary's assistant at Geneva, where he attended the lectures of de Candolle, de la Rive and Pictet; under Humboldt's advice he went to Paris, where he became a lecture-assistant under Thenard, then professor successively at the Athenæum and Ecole Polytechnique and

finally in 1835 Gay-Lussac's successor at the Sorbonne (University of Paris). The well-known method of estimation of nitrogen was published by him in 1833.

Dumas' contemporary, Friedrich Wöhler (1800-1882) was a medical student at Heidelberg. From the beginning of his studies he devoted himself to chemistry and improvised a miniature laboratory at his landlady's room at Marburg, and on L. Gmelin's advice he proceeded to Stockholm to study chemistry under Berzelius, the great Swedish chemist, after becoming a Doctor of Medicine in 1823. To quote Wöhler himself: "L. Gmelin, however, was of opinion that I should do as he had done, give up medicine which is uncertain and remain a chemist." Berzelius at that time held a unique position in the chemical world and was regarded as its unquestioned sovereign and dictator. His laboratory at Stockholm was a place of pilgrimage as it were to the votaries of our science. He proceeded to Lübeck in order to go to Stockholm by sea. There was only a small sailing boat for Stockholm in the harbour which was to start three weeks later. It did not start, however, within six weeks. Here Wöhler met the apothecary Kindt, who had a good scientific training and considerable interest in all science. Wöhler spent the last three weeks of his

stay at Lübeck with Kindt and in his washing-room he prepared potassium according to the newly published method of Brunner. This he took with him to Berzelius to whom it was useful in his researches on silicon, boron and zirconium. At last the ship sailed and after a very stormy passage the Swedish coast was reached. The journey over, Wöhler asked through an interpreter, an old soldier, how much he would have to pay for the passage. The Captain's reply was that he had too high regard for science and for his countryman Berzelius to take any money from one who was undertaking such a long journey for purposes of study.

Berzelius welcomed Wöhler heartily and the latter began work on the very next day. The impression created in the mind of Wöhler when he first met the great Swedish chemist and his description of the laboratory are well worth quoting in his own words: "With a beating heart", says Wöhler, "I stood before Berzelius's door and rang the bell. It was opened by a well-clad, portly, vigorous-looking man. It was Berzelius himself. . . . As he led me into his laboratory I was as in a dream, doubting if I could really be in the classical place which was the object of my aspirations. . . . . I was at that time the only one in the laboratory; before me were Mitscherlich and Heinrich and Gustav Rose; after me came

Magnus. The laboratory consisted of two ordinary rooms furnished in the simplest possible way; there were no furnaces or draught places; neither gas nor water service. In one of the rooms were two common deal tables; on one of these worked Berzelius, the other was intended for me. On the walls were a few cupboards for the reagents; in the middle was a mercury trough, whilst the glass-blower's lamp stood on the hearth. In addition was a sink, with an earthenware cistern and tap, standing over a wooden tub where the despotic Anna, the cook, had daily to clean the apparatus. In the other room were balances, and some cupboards containing instruments; close to was a small workshop fitted with a lathe. In the neighbouring kitchen, in which Anna prepared the meals, was a small but seldom used furnace and the never-cool sand-bath." In short, Anna the kitchen-maid was the maid-of-all-work,—maid, cook and laboratory servant all combined in one. Wöhler remained in constant correspondence with Berzelius till the latter's death in 1848. The translation of Berzelius' *Jahresbericht* (Annual Report on the Progress of Chemistry) and text-books was with him a labour of love. "By undertaking the translation of his annual reports and his text-books although it took much time, I hoped to give an expression to my gratitude and piety towards my paternal

friend." In fact, the relation between the teacher and the pupil was as between father and son.

In our cursory review it is not possible to do anything like justice to the eminent services rendered by Wöhler to the growth and development of organic chemistry. One instance will I hope suffice to give you an idea of the great revolution he effected in this branch. Before his time it was the general belief that products like sugar, gum, indigo, urea etc., could only be formed through the agency of the so-called *vital force*, *i.e.*, the metabolic change in the tissues of plants and animals. Wöhler prepared ammonium cyanate and showed that when its solution in alcohol is evaporated it is transformed into *urea*—a body hitherto obtained by the evaporation of urine with nitric acid. A little less than a century ago the building up of complex organic compounds like indigo, alizarine and the numerous dyestuffs from very simple components could not be dreamt of. By his epoch-making discovery Wöhler for the first time obliterated the arbitrary distinction between organic and inorganic chemistry and laid the foundation of synthetic organic chemistry, which has now attained to gigantic proportions.

The name of Wöhler is indissolubly connected with that of Justus von Liebig

(1803-73), who began life as an apothecary's assistant and later studied chemistry under Kastner at Bonn and Erlangen. On receiving a scholarship Liebig went to Paris and joined the laboratory which was formerly under Vauquelin. Later on he joined Gay-Lussac's laboratory. Liebig while working here proved that fulminic acid and cyanic acid—though they differed widely in properties—were identical in chemical composition. This was the first instance of the discovery of *isomerism*. Gay-Lussac was so much overjoyed at the success of his youthful pupil that he actually took him into his arms and whirled about the room in the manner of a waltz. At the early age of twenty-one he became professor at Giessen on Humboldt's recommendation and here he fitted up his celebrated laboratory.

The first theory, which permitted the grouping together of a number of organic compounds under one head, was the Aetherin Theory of Dumas and Boullay. Williamson's memoir on etherification published in 1852, did much to advance the use of chemical types, and therefore to undermine the dualistic system of Berzelius. The classical researches of Liebig and Wöhler on the radical of benzoic acid brought the theory of compound radicals to the forefront although Lavoisier's idea that in organic substances the radicals consist of two or more elements was strikingly con-

firmed for the first time by Gay-Lussac's researches on hydrocyanic acid and the discovery of cyanogen. The radical theory received later powerful support from Bunsen's researches on cacodyl derivatives and by his isolation of cacodyl itself.

Robert Bunsen (1811-1899) was the son of a university librarian of Göttingen, who was at the same time a professor of philology. He studied chemistry first at Göttingen and then at Paris where he attended the lectures of Gay-Lussac and came into intimate contact with Regnault. After spending sometime in Vienna and Berlin he became a Private-docent at Göttingen. In 1836 he succeeded Wöhler at Kassel and in 1839 occupied the chair of chemistry at Marburg, in 1851 at Breslau and in 1852 at Heidelberg. He retired in 1889 and died ten years later. Frankland at Marburg and Roscoe at Heidelberg studied under Bunsen and caught his inspiration and thus carried the torch to England.

The theory of substitution was formulated in the proper form by Dumas although its origin may be traced to Gay-Lussac, who investigated the action of chlorine on wax, fats and fatty acids in the twenties of the nineteenth century and communicated the result in his lectures to the students. In the second volume of his course of chemistry we find the following note of a lecture delivered

on the 16th July, 1828. "When one introduces chlorine in the gaseous state to the oils it displaces from the latter one portion of the hydrogen with which it combines to form hydrochloric acid, which can be collected; and at the same time a portion of the chlorine combines with oil and takes the place of the hydrogen displaced, so that one has a different inflammable substance."* Dumas discovered the empirical laws of substitution in the course of his researches on the action of chlorine on terpentine. The theory of substitution was further developed by his eminent pupils, Laurent and Gerhardt.

Aguste Laurent (1807-53) was the son of an ordinary peasant. In 1826 he became an external student at the School of Mines and in 1831 assistant at the Ecole Centrale des Arts et Metiers of which Dumas was professor and in whose laboratory he carried on his first investigations. In 1838 Laurent became professor at the Faculty of Science at Bordeaux. He came back to Paris in 1846 and became assayer at the mint, but his income and opportunity for work were very limited and he was always in straitened cir-

* The substitution of hydrogen by chlorine in several compounds had been observed by Gay-Lussac and communicated by him in his lectures to his students but when his lecture notes were copied at the instance of a firm of publishers they had to be revised by Gaultier de Claubry as Gay-Lussac refused to have anything to do with the speculation.

cumstances. He died of tuberculosis in 1853. His biographer Grimaux writes of his unfortunate career in this strain. "He spent his life in constant labour in the disinterested investigation of truth, a prey to malevolent critics and coarse attacks. He knew neither fortune nor honour nor even the joy of seeing the triumph of the doctrines for which he had fought without relaxation."

Laurent's friend and co-worker Charles Gerhardt (1816-56) was born in a brewer family. At the age of twenty he joined Liebig's laboratory and two years later he went to Paris where he attended the lectures of Dumas and Despretz. Only occasionally could he work in Chevreul's laboratory; in 1855 he became professor of chemistry at Strasbourg but died of acute peritonitis a year later. His relation with Laurent has been admirably summed up by Wurtz in the following words: "La grande figure de Gerhardt ne sera point separée de Laurent, leur œuvre fut collective, leur talent complementaire, leur influence reciproque." (The grand figure of Gerhardt cannot be separated from that of Laurent; their work was joint, their talents complementary, their influence reciprocal).

Stereochemistry owes its origin to the researches of Louis Pasteur (1822-95) on the salts of tartaric and racemic acids. Pasteur was the son of a poor tanner. His early life

was uneventful and gave no indication of his brilliant future. Remarkable, however, was his aptitude for drawing, which gave Pasteur a reputation as a painter among his co-villagers and it is possible that his eye for the external forms of bodies sharpened by his youthful exercises was of considerable assistance in his crystallographical and morphological studies. Young Pasteur was anxious to go to Paris and study at the Ecole Normale and obtain the Bachelor's degree. "In 1842 Pasteur had been examined for a degree in science but had not taken a good place, being only 'moderate' in chemistry and low on the list for the Ecole Normale. This determined him to read more and to offer himself again for examination, and with this end in view he attended Dumas' lectures at the Sorbonne. 'You can imagine,' he wrote home, 'what a crowd of people come to these lectures. The room is immense, and always quite full. We have to be there half an hour before the time, to get a good place, as you would in a theatre; there is also a great deal of applause, there are always six or seven hundred people'" (Hammond).

His attention was early drawn to the relation between the chemical composition and physical properties of substances and as among these crystalline form appeared to be very important, he began the study of

crystallography and as an exercise repeated the work of de la Provostaye on the forms of tataric acid, racemic acid and their salts. His sharp observation did not fail to notice that in the tartrate crystals there are hemihedral facets, the one being the mirror-image of the other. The idea that there might be some connection between the presence of hemihedral facets and the well-known optical property of tartaric acid in contradistinction to racemic acid led Pasteur to repeat an experiment performed by Mitscherlich in 1844. Mitscherlich had investigated the sodium amonium salts of tartaric acid and racemic acid and observed that they were identical. Pasteur found, however, that the racemate contained crystals with hemihedral facets some to the right, others to the left, while in the tartrates the facets were all on the same side. The crystals could be separated mechanically and the acids liberated from the salts also showed a difference in optical activity. At first Pasteur's researches were regarded with scepticism specially by Biot, the eminent physicist, who had done valuable work on the polarisation of light. Pasteur had to repeat the experiment under Biot's supervision and when it was successfully concluded, the venerable old man, who was much touched, congratulated Pasteur with the words, "My boy, I have loved the sciences too well for

this to break my heart." In 1858, Pasteur observed the partial fermentation of racemic acid by some yeast-like micro-organisms, which indicated the significance of a molecular asymmetry for physiological processes.

In the lives of great men of science three distinct epochs may generally be noticed. The first epoch consists of the period of strenuous pioneering work when they open up new avenues for the future generations. The second epoch begins when they gather pupils about them who carry the master along with them. The youthful geniuses, no doubt inspired by the master, can give free play to their energies and usually see further standing, so to say, on the shoulders of the master, and thus they generally leave him far behind. Then begins the third epoch when we often find a bitter struggle between the master and the pupils. The former, especially if he lives to an advanced age, has sometimes the misfortune of seeing his cherished ideas and pet theories called in question and shaken and even subverted by his own pupils and if he has not the prudence of retiring from the strife in time, an embittered old age is the result. The infirmities of great men should not be the occasion for mischievous delight. On the other hand, it should make us bow down our heads in all humility as indicating the limitations of human character. One or

two instances in illustration of this aspect may be cited here. Berzelius and the dualists maintained that if hydrogen is substituted by chlorine the chemical character of the product must be entirely different from that of the original product. But when Laurent and Gerhardt pointed out the untenability of the cherished electro-chemical system by showing that a body like acetic acid does not lose its characteristic acid properties by the successive replacement of one, two or three of its positive hydrogen atoms by negative chlorine atoms, the Swedish chemist simply grew furious and was even heard to exclaim: "Damn the French chemists!" It is only fair to add that some great masters at any rate have accepted the overthrow of their hypothesis by their pupils and by young novices sportsmanlike and with good grace (*cf.* Berthollet's behaviour towards Gay-Lussac and Biot's towards Pasteur). I feel here tempted to quote the ideal of the Hindu *gurus* (teachers) of old:

सर्व्वत्र जयमन्विच्छेत् पुत्रात् (शिष्यात्) पराजयम् ।

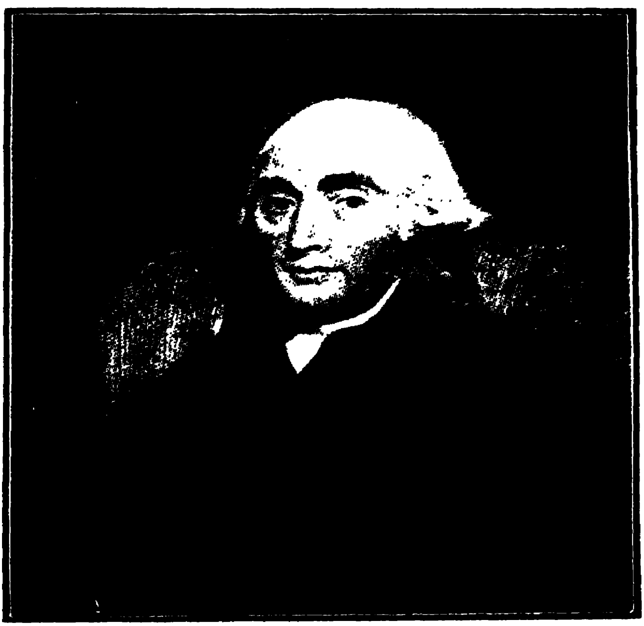
"When one enters the lists he naturally wishes to vanquish his antagonist. But when the latter happens to be his own pupil, he would fain court defeat."

LECTURE V

Dalton—His struggles with poverty—Laws of Definite and Multiple Proportions—Dalton's Atomic Theory.

Another remarkable personality to whom the progress of modern chemistry is largely due is John Dalton (1766-1844). He belonged to the Society of Friends (the quaker community). His father was a poor weaver. He was practically self-taught. In his early days "he earned his living by setting up a school where his pupils were boys and girls of all ages, from infants whom he held on his knee while he taught them their letters, to robust youths who met his reprimands with pugilistic challenges. The weekly pence gathered from them to the total amount of about five shillings were eked out with the sale of stationery; while his own education was pursued with a zeal examplified by his copying out verbatim a number of the Ladies' Diary which fell into his hands. He supported himself by giving private lessons in mathematics at half a crown an hour besides performing analysis and doing other work as a professional chemist at ridiculously low charges. His wants were few and his habits economical to the verge of parsimony, yet he could be generous on occasions." Late in life a pension of £150 a year increased to £300 in 1836

Dalton



Black

relieved him from the drudgery of teaching. Asked the reason why he had not married, he replied, "I never had time." Dalton, however, assiduously devoted himself to private studies and one of his biographers relates that during the twelve years of his life as an assistant teacher at Kendal (1781-93) he probably read more than in the fifty of his remaining life. Metereology was his hobby and he, for the first time, made the novel assertion that aqueous vapour exists in the air as an independently elastic fluid, not chemically combined, but mechanically mixed with the other atmospheric gases, and continuing his researches on this line he discovered the Law of Partial Pressure. Dalton suffered from the defect of colour-blindness and hence this disease is known as *Daltonism.* From metereology Dalton progressed by easy steps to chemistry.

Dalton was a clumsy experimenter but he had the rare gift of almost intuitive, nay prophetic vision. Since the days of Lavoisier, who as we have seen placed chemistry on modern scientific basis, its progress had been rapid, a large number of facts had accumulated but they were in a mess or jumble. Indeed, a man endowed with powers of generalisation was badly wanted who would evolve something like cosmos out of chaos. There were at that time two different

schools of chemistry. One led by Berthollet maintained that two or more elements might combine with one another in any indefinite proportion by weight, while the other led by Proust asserted with equal pertinacity that they combine only in deinite weights. Here I may observe that in the Hindu Pharmacopœia of the ninth century and onwards the former view prevails. Thus Chakrapani in the preparation of the black sulphide of mercury (Kajjvali) or Aethiop's mineral says:—Take equal parts by weight of mercury and sulphur respectively, put them (by instalments) in a mortar and rub continuously and cautiously till both are reduced to fine powder. We know that twenty-five parts by weight of mercury only can enter into combination with four parts by weight of sulphur. The excess remains in the free state; indeed, if the Kajjvali be shaken up with a little carbon bisulphide and the filtrate allowed to evaporate off fine crystals of sulphur will begin to put in an appearance. The same weight of a metal, however, was known to combine with different weights of sulphur, for instance, three distinct sulphides of iron are known to exist in nature to which we now assign the formulæ, FeS, FeS_2, Fe_2S_3 respectively; copper has also two sulphides, namely, cuprous (Cu_2S) and cupric (CuS) sulphides. There are also several oxides of

manganese, *e.g.*, MnO, Mn_2O_3, Mn_3O_4, and MnO_2. The last occurs in nature and is called pyrolusite, the oxide from which Scheele prepared, as we have already seen, oxygen and isolated the metal manganese itself. "Proust proved conclusively that Berthollet's views were not generally applicable, inasmuch as he showed that when one metal gives rise to two oxides, the weight of the metal which combines with the same quantity of oxygen to form the various oxides is a different but a fixed quantity, so that combination does not take place by the gradual addition of one element, but by sudden increments. His observations might in fact have led him to the recognition of the law of multiple proportions, but his analyses were not sufficiently accurate for this purpose."

Dalton's philosophic mind clearly perceived that order was Heaven's law and that two elements are not likely to combine in any proportion in a haphazard manner. Unfortunately, when he took up this subject, *i.e.*, about the year 1800, the methods of chemical analysis were imperfect and what is now known as the chemical balance was then rather crude in construction; but from the data at his disposal and as the results of his own analyses of compounds he was in a position to enunciate the following laws: Matter is composed of ultimate indivisible particles

called atoms and a compound is formed by the juxtaposition of these particles. This conception however dates from a remote antiquity and is to be met with in the writings of the old Greek and Hindu philosophers and to this Dalton added: Each atom has its own fixed combining weight. If, however, two elements combine in more than one proportion by weight they combine in integral multiples of these weights. These are called the *Law of Definite Proportion* and the *Law of Multiple Proportion.* The gradual recognition of these two laws forms the basis of modern theoretical chemistry. It is but fair to add that the great Swedish chemist Jacob Berzelius, who was a past master in analytical chemistry, subjected Dalton's laws to crucial and rigid test and placed them on an unshakable basis. For a period of five years (1808-1812) Berzelius performed his self-imposed task "with consummate skill, undaunted patience and great accuracy"; in what spirit he approached it will be evident from his own memorable words: "the hypothesis of Dalton, if firmly supported by facts, would be the greatest advance chemistry had yet made towards its perfection as a science."*

* It is interesting to note that the origin of the Daltonian hypothesis can be traced to the writings of Jean Rey, who says: "The weight with which each portion of matter was endued at the cradle, will be carried by it to the grave. In whatever place,

From a careful study of the manuscripts of Dalton preserved in the rooms of the Manchester Literary and Philosophical Society, Roscoe and Harden have been led to conclusions concerning the origin of the atomic theory of chemistry which differ widely from those which have been generally accepted. He appears to have been mainly influenced in the development of his theory by the consideration of the physical properties of gases, and more especially by his attempts to account for the various phenomena of the diffusion and the solubility of gases, rather than by the results of any extended series of chemical analyses.

His views on these subjects, in fact, led him to endeavour to ascertain the relative sizes of the particles in different gases, and this involved the determination of the relative weight of the particles of each gas and the relative number contained in a given volume. It was with the object of determining this relative weight that he had recourse to the chemical composition of the gas, and was thus led to the ideas which he formulated as the Atomic Theory.

As early as 1802, in an experimental inquiry into the proportions in which the several gases constituting the atmosphere

in whatever form, to whatever volume it may be reduced, the same weight always persists."

occur, Dalton clearly points out "that the element of oxygen may combine with a certain portion of nitrous gas" (our nitric oxide) "or with twice the portion, but with no intermediate quantity," and this observation, no doubt, also contributed largely to the development of his views.

LECTURE VI

India's gifts to the world—Chemical processes of the ancient Hindus—Identification of metals—The Hindu method of extraction of zinc—Sodium and potassium carbonates—Mild and caustic alkalis—The *Susruta* and Joseph Black—Black sulphide of mercury.

An eminent Belgian Indologist, Goblet d'Alviella, has very justly observed that India is a land of paradoxes, that whatever is of ancient origin excites our admiration—her literature including her unrivalled dramas, her transcendental philosophy of the *Upanishads* and the *Geeta* attracted the attention of the West long ago. India was once the cradle of mathematical sciences including arithmetic and algebra; the system of notation, popularly ascribed to the Arabs, is really the product of the Hindu brain.

Max Müller says somewhere that if India had presented no other gift to Europe than that of the numerals, the debt of the latter to the former would have been unrequitable.[1]

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[1] The learned professor of Sanskrit of Oxford University says: "In science too, the debt of Europe to India has been considerable. There is, in the first place, the great fact that the Indians invented the numerical figures, used all over the world. The influence which the decimal system of reckoning dependent on those figures has had not only on mathematics, but on the progress of civilisation in general, can hardly be overestimated. During the 8th and 9th centuries the Indians became the teachers in arithmetic and algebra

Ancient Assyria, Babylon and Egypt exist only in their monuments, cuneiform inscriptions or hieroglyphs, inscribed on slabs of stone or baked clay. The recent discoveries in Tutankhamen mausoleum have yielded many new specimens of Egyptian art of all kinds. Rome and Greece live in their literature and philosophy, but the Hindu nation persists to-day as it did 2,500 years ago, when Gautama Buddha preached at Benares, the sacred city of the Hindus. Sakya Muni knew that if he could make a breach in the citadel of Hindu religion and culture, the whole of India would readily embrace his new doctrine. For a time Brahminical supremacy must have been shaken to its foundation as is proved by the archæological findings of Sarnath. But the tenacious vitality of the Hindu religion is something marvellous and it struck sagacious tourists and observers like Pierre Loti. Even to-day European visitors who find the pious Hindu performing his daily religious practices and ablutions at the bathing ghats of the Ganges can have but little difficulty in coming to the conclusion that impact with the West has scarcely produced any effect on the Hindu. He pursues his daily even tenor of life as his

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of the Arabs and through them of the nations of the West. Thus, though we call the latter science by an Arabic name, it is a gift we owe to India".—Macdonnell's *History of Sanskrit Literature*, p. 424.

ancestors did twenty-five centuries ago. No wonder that the poet should exclaim :—

"The East bowed low before the blast
In patient, deep disdain,
She let the legions thunder past
And plunged in thought again."

No doubt the Hindus have been meditating—ever lost in abstruse metaphysical subtleties, but, all the same, in ancient India physical science found her votaries. I have barely time to allude to the atomic theory as propounded in the Vaiseshika System of Kanada, which anticipates the doctrine of Anaxagoras, Empedocles, etc. I shall limit myself this afternoon to the keen powers of observation as also the necessity of experimental methods enjoined by the Hindus of old, so far as chemical processes are concerned. Indeed, Dhundukanatha, the author of the standard iatro-chemical treatise *Rasendra Chintamani*, (lit. gems of mineral preparations), says : "They are alone to be regarded as real teachers who can show by experiment what they teach. They are the deserving pupils, who, having learnt the experiments from their teachers can actually perform them. The rest, both the teachers and the pupils, are merely stage-actors."[1]

1 यच्छ्रौषं बहुविदुषां मुखादपास्तं
शास्त्रेषु स्थितमकृतं न तल्लिखामि ।
यत् कर्म व्यरचयमग्रतो गुरूणां
प्रौढ़ानां तदिह वदामि वीतशङ्कः ॥

This author, again, acknowledges his indebtedness to the standard work on the subject, *Rasarnava*, in which occurs an elaborate account of the processes of sublimation, distillation, etc., as also of the apparatus required for the process. Indian alchemists are also eloquent in their veneration for and indebtedness to the great adept, Nagarjuna, to whom is ascribed the invention of the above processes. One instance will suffice to give you an idea of the methods adopted for the purification of mercury.

मिश्रितौ चेद्रसे नागवङ्गौ विक्रयहेतुना।
ताभ्यां स्यात्कृत्रिमो दोषः तन्मुक्तिः पातनत्रयात्॥

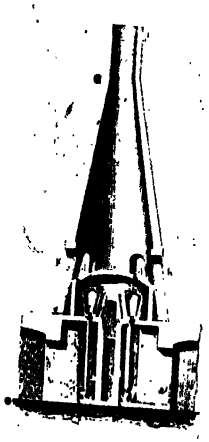
The above, literally rendered, runs as follows: "Fraudulent dealers adulterate (alloy) mercury with lead and tin, hence these impurities are to be removed by subjecting the mercury to triple distillation."

The identification of metals by the colouration of their flames is referred to in *Rasarnava*—

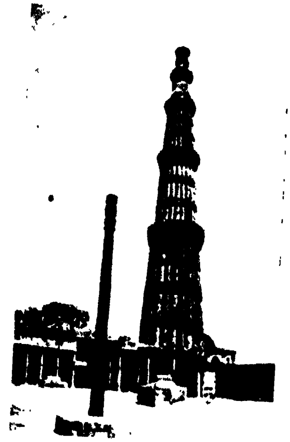
"Copper yields a blue flame, that of tin is pigeon-coloured, that of lead is pale tinted[1]............" We are not aware of similar

अध्यापयन्ति यदि दर्शयितुं क्षमन्ते
सूतेन्द्रकर्मगुरवो गुरवस्त एव।
शिष्यास्त एव रचयन्ति गुरोः पुरो ये
शेषाः पुनस्तदुभयाभिनयं भजन्ते॥

1 *Cf.* "Lead compounds impart a pale tint to the non-luminous gas flame."—Roscoe and Schorlemmer's *Chemistry*, Ed. 1879.



A modern method of extraction of zinc



The iron pillar and the Kutab minar near Delhi

Fumigating apparatus

Extraction of zinc from calamine

tests being applied anywhere at such an early period as a qualitative test for metals.[1] As regards the high degree of skill in metallurgy attained by the Hindus, it is enough to mention the iron pillar near Delhi.[2] In the ancient Hindu literature only six metals are mentioned, *viz.*, gold, silver, iron, lead, tin and copper. The name of a seventh metal—zinc —occurs in European history for the first time in the works of Paracelsus, who leaves us in the dark as to the nature of his "zincken," which he designates as "semi" or bastard metal.

Libavius was the first to mention the pro-

1 Cardan (1501-1576) is perhaps the earliest to notice that the colour of the flame varies with different metals—Hoefer's *Hist. d. Chim.* Vol. II, p. 95. Ed. 1869.

2 "Taking A.D. 400 as a mean date—and it certainly is not far from the truth—it opens our eyes to an unsuspected state of affairs to find the Hindus at the age capable of forging a bar of iron larger than any that had been forged even in Europe up to a very late date. As we find them, however, a few centuries afterwards using bars as long as this *lat* in roofing the porch of the temple at Kanaruc, we must now believe that they were much more familiar with the use of this metal than they afterwards became. It is almost equally startling to find that, after exposure to wind and rain for fourteen centuries, it is unrusted, and the capital and inscription are as clear and as sharp now as when put up fourteen centuries ago."

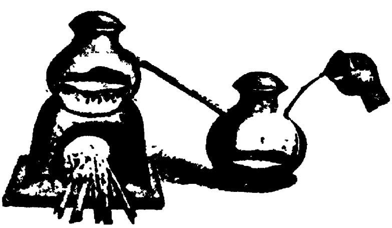
"There is no mistake about the pillar being of pure iron. General Cunningham had a bit analysed in India by Dr. Murray and another portion was analysed in the School of Mines here by Dr. Percy. Both found it pure malleable iron without any alloy"—Fergusson's *History of Indian and Eastern Architecture*, Ed. 1809, p. 508. Even now forged masses of such size are exceptional (see p. 110).

perties of zinc more exactly although he was not aware that the metal was derived from the ore known as 'calamine.' He states that "a peculiar kind of tin is found in the East Indies, called 'calaëm.' Some of this was brought to Holland, evidently by the Dutch East India Company, and came into his hands." The extraction of zinc from the ore (calamine) can be followed in every detail from the account left to us in *Rasarnava* and specially in *Rasaratnasamuchchaya.* The process as given in the latter work is reproduced below. The literal rendering of it runs thus :

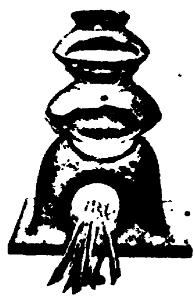
"Rub calamine with turmeric, the chebulic myrabolans, resin, the salts, soot, borax[1]......... Fill the inside of a crucible with the above mixture and dry it in the sun. Close its mouth with a perforated saucer. A vessel filled with water is embedded in the ground, over which the above vessel charged with the mixture is inverted, which is again heated as shown in the figure, by means of a charcoal fire. The operation is stopped when the *flame issuing from the mass changes from blue to white.* The essence of the metal, which drops into the water and has the lustre of tin, is to be collected." Indeed, the process, so elabor-

[1] It is scarcely necessary to point out that highly carbonaceous substances like resin, turmeric, etc., being heated in absence of air, yield carbon in a fine state of division.

Apparatus for sublimation and
distillatio per descensum.



Apparatus for
distillation



Apparatus for extraction
of mercury from cinnabar

ately given above, might be quoted almost *verbatim* in any treatise on modern chemistry.[1] It is practically the same as *distillatio per descensum*—the flame of a bluish tint issuing from the mouth of the crucible indicates the combustion of carbon monoxide so often observed in metallurgical operations.

It is not, of course, claimed that the ancient Hindus knew that the blue colour was due to the combustion of carbon monoxide, but what I should like to lay particular stress upon is the power of keen observation underlying the description.

The ancient Hindus knew the distinction between potassium carbonate and sodium carbonate—the former is called *yavakshara* (lit. ash from the spikes of barley), and the latter *sarjikakshara*, (equivalent to *natron* from Egypt). The earliest record of this is to be found in the old Hindu work, the *Susruta*. The *Charaka* and the *Susruta* are the two standard and authoritative treatises on *Ayurveda* (lit. science of life). The *Charaka* is more concerned with medicine, while the *Susruta*

1 *Cf.* "A mixture of two parts of ground roasted ore and one part of coal-dust is brought into the retorts, each holding about 40 pounds of the mixture. As soon as the temperature has risen high enough, the reduction begins and *carbon monoxide* is evolved and burns from the end of the clay adapter with *a blue flame.*" (The italics are ours)—Roscoe and Schorlemmer's Chemistry, Ed. 1879, Vol. II, Part I, p. 225.

relates more or less to surgery. Here we have a drop of 2,000 years from the *Susruta* to the remarkable discoveries of Joseph Black. In the *Susruta* the two modifications of alkali are referred to as *tikshnakshara* (*tikshna*, *i.e.*, sharp or caustic; *kshara*, *i.e.*, alkali), and *mridukshara* (*i.e.*, mild alkali). The distinction between the two is quite clear. In the days of my boyhood the ashes of the plantain tree (*Musa sapientum*) were used by washermen for cleaning clothes. The reason is that it is very rich in potassium carbonate. In the *Susruta* we have many land plants mentioned which have been botanically classified in Uday Chand Dutt's *Materia Medica of the Hindus*. The *Susruta* says: "On an auspicious day cut the plant down, burn it and boil the ashes with water in an iron pan and then filter through cloth folded several times." This, says the *Susruta*, is *mridukshara*. You know what actually takes place in this process. The clean solution that is obtained is rich in potassium carbonate and is termed mild alkali.

Next comes the description of the preparation of caustic alkali, and this is the most scientific portion. "Collect several kinds of limestone and shells and burn them strongly and add water to the resulting product. Next mix this slaked lime with the lixiviated liquid obtained above and boil and stir with an iron ladle." The reactions that take place here can

be represented in the modern way by the following equations:

$$CaCO_3 = CaO + CO_2$$
$$CaO + H_2O = Ca(OH)_2$$
$$K_2CO_3 + Ca(OH)_2 = 2KOH + CaCO_3$$

This method, you will look for in vain in any European treatise before the 16th or the 17th century. The process as given in the *Susruta* is so scientific that it can be bodily transferred to any modern text-book on chemistry. Besides recommending the use of an iron vessel for boiling the liquid, the book further says that the *kshara* so obtained, must be stored in an iron vessel with its mouth closed:

आयसे कुम्भे संवृतमुखे निदध्यात् ।

The *Susruta* cannot, of course, be credited with having known that carbon dioxide was to be excluded from the vessel to prevent the caustic solution from being acted upon. But the physicians of those days must have certainly realised by empirical methods that the causticity would be diminished if these precautions are not taken. Even to-day we keep caustic potash either in iron or silver vessels. The points to be noted here are that the *Susruta* gives not only a very accurate method of preparation and preservation of the two kinds of alkali but also the distinction between the two varieties, *tikshnakshara* and *mridu-kshara*, is clearly recognised. Davy isolated

potassium and he says, "The ancients did not know how to distinguish between potassium carbónate and sodium carbonate." But in our *Ayúrveda* this sharp distinction has been clearly stated.

Between the *Susruta* and Joseph Black lies a gap of some 2,000 years. Black was an M.D. of Edinburgh. In his Doctorate thesis (presented in 1755) he gave, for the first time, the scientific explanation of the difference between caustic and mild alkalis. He heated magnesium carbonate using the balance at each stage of the experiment, and pointed out that on strong heating there was a loss in weight. He also pointed out that a gas was given out which was called "fixed air." Ramsay in his *Life of Black* says: "Quicklime is formed by heating lime-stone in the fire; it thereby acquires its burning properties or causticity." Black's essay was an epoch-making one.

M. Berthelot, under whose inspiration I took to writing my *History of Hindu Chemistry*, in reviewing my book says of this portion "that the Hindus possibly got their knowledge of this method from the Portuguese" (*Journal des Savants*, Jan., 1903, p. 34). But against that I may point out that Chakrapani, who was the court physician of Nayapala (1050 A.D.), King of Gour, in the treatise which goes by his name, quotes this mode of prepara-

tion verbatim from the *Susruta*. A much older treatise, the *Vagbhata*, also does the same. In the course of my studies, I came across a remarkable passage in a Buddhist work which dates as far back as 140 B.C.,—I mean the *Milinda Panho*. Professor Rhys Davids translates the portion as follows: "And when the inflammation had gone down and the wound had become sweet, suppose he were then to cut into it with a lancet, and burn it with caustic. And when he had cauterized it, suppose he were to prescribe an alkaline wash. .... Now tell me, O King! would it be out of cruelty that the surgeon......... thus cut with the lancet and cauterized with the stick of caustic."[1]

It must be admitted on the other hand that the discovery of Black was quite independent and he showed that the difference between the mild and the caustic alkalis was due to the presence of carbon dioxide in the former. The *Susruta*, of course, does not say anything of this kind.

The use of metallic preparations mentioned in the Hindu Pharmacopœia also dates from a very early period. In Europe Paracelsus was, as we have said, the first to introduce metallic preparations into medicine. But in India, Vrinda who preceded Chakrapani by at least a century and therefore must have

1 *Sacred Books of the East*—Vol. XXXV, p. 168.

flourished about the 9th century A.D., or even earlier, was the first to prescribe 'Kajjvali' (black sulphide of mercury) as a medicine. Chakrapani gives an elaborate description of the process of making 'Kajjvali' (*vide* p. 74). In Europe this preparation was not known before the 17th century.[1]

I need not proceed further. The knowledge of pharmacy which the Arabs brought to Europe was derived from the Hindus. *Ex oriente lux.* I shall conclude with the apposite words of the illustrious French chemist, Jean Baptiste André Dumas: "What an awakening for Europe! After two thousand years she found herself again in the position to which she had been raised by the profound intellect of India and the acute genius of Greece." (The first *Faraday Lecture* delivered before the Chemical Society, June 17, 1869).[2]

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1 Das schwarze Schwefelquecksilber lehrte zuerst Turquet de Mayerne, im Anfange des 17 Jahrhunderts, durch Zusammenreiben von warmen Quecksilber mit geschmolzenem Schwefel darstellen" —Kopp: *Gesch. d. Chem.* Vol. IV, p. 186.

2 Hoefer in his admirable *Histoire de la Chimie* also expresses the same view: "L'Inde est le bercean de la filiation des peuples qui merchent à la tête de la civilisation."—Vol., I, Ed. 1866.

THE STORY OF THE DISCOVERY OF OXYGEN.

Early lives of Priestley and Lavoisier compared—Advantages of Lavoisier over Priestley—Lavoisier explains the so-called transmutation of water into earth—Combustion of diamond—The rôle of air in the phenomenon of burning—Boyle's view overthrown—Bayen's experiments with mercuric oxide—Priestley's classical experiment—Lavoisier repeats Priestley's experiment—Who is the discoverer of oxygen?—Priestley, a phlogistian—Eck de Sulzbach's experiments with mercuric oxide—The rival claims of Priestley and Lavoisier—A parallel case.

In ordinary text-books it is customary to dispose of the rival claims of Lavoisier and Priestley cavalierly and in a summary fashion. The former is often held up to public opprobrium as a plagiarist, as one who heard of the discovery of oxygen from the lips of Priestley himself but forgot to acknowledge his obligations and thus indirectly and by implication at any rate claimed it as his own. As this vexed question has been puzzling the brains of many an historian of chemistry for the last century and a half it is much to be desired that a final and definitive solution, if possible, should be arrived at.

Priestley, as I have already said, was a born theologian, a controversialist and a linguist to boot. He pursued chemistry simply as a recreation during his leisure hours and thus had to approach the subject with-

out any previous systematic training. As he himself candidly admits: "Had I been anything of a practical chymist, I could not have entertained any such suspicion about mercurius calcinatus on which I had made my experiments." On another occasion in describing the *air from nitre* he says: "This series of facts, relating to air extracted, seem very extraordinary, and important, and *in able hands* (the italics are ours) may lead to considerable discoveries." Moreover, he had to struggle with poverty, and much of his time was taken up in earning his livelihood as a pastor or tutor. Lavoisier, on the other hand, was born in an opulent family and his father spared no pains to give his son the benefit of a liberal education. He studied mathematics and astronomy, mineralogy and geology as also botany at the feet of eminent professors and was initiated into chemistry by Rouelle, whose fame as an exponent of the science had attracted pupils from far and near. Besides Lavoisier, Rouelle could boast of such illustrious pupils as Bucquet, Bayen, Macquer and Darcet—each and all of whom made their mark as eminent chemists towards the close of the eighteenth century.

There was thus a decided initial advantage on the side of Lavoisier, whose intellectual equipment enabled him to see things in their true perspective. Priestley

often improvised his experiments in a crude manner and performed them clumsily and was led to draw wrong conclusions. We shall select some typical instances to illustrate the difference in the mental outlook of each of these great precursors of our science.

Lavoisier started his career as a chemist when he was barely twenty-seven and his first classical experiment (1772) imparted a rude shock to the then current notions about the constitution of matter. From the time of the old Greek and Hindu philosophers it was held that matter was composed of the four (according to the Hindu, five including *byom* or ether) elements and that these were convertible into one another. Chemists had often noticed that when distilled water was evaporated off even in a clean glass vessel there was invariably a solid residue left. This result was vaguely interpreted as the transmutation of water into earth. Lavoisier caused water to be boiled in a specially devised glass vessel for three months, day and night. He weighed the glass vessel very carefully both before and after the experiment as also the evaporated (distilled) water and the residue and proved conclusively that the weight of the latter was exactly equal to the diminution in weight of the glass vessel—in other words, that the water invariably dissolves a portion of the glass as is now

known to every chemist. It should be noticed that *Lavoisier used the balance as his guide in this as in all his subsequent experiments.* He next took up the question of combustibility of diamond. Darcet, Rouelle, Macquer, Boyle, as also the physicists under the patronage of the Grand Duke of Tuscany had already demonstrated that this precious stone when strongly heated on a porcelain dish slowly disappeared.* Lavoisier in collaboration with Macquer and Cadet proved that diamond when prevented from coming into contact with air remained intact and legitimately concluded that it was a case of ordinary combustion like that of charcoal. But the ground was not yet ready for the full and satisfactory explanation, as oxygen had yet to be discovered. The succeeding two years were equally eventful. He burnt phosphorus in a closed vessel and found that one-fifth of the volume of air disappeared and the residual air was quite different from the ordinary air and was unfit for respiration; and knowing the specific gravity of the air he could con-

* There was, however, considerable difference of opinion as regards the cause of this phenomenon, the generally accepted view being that the daimond like phosphorus volatilised away (*vide Hist. Hindu Chem.*). It was in 1775, *i.e.*, after the discovery of oxygen, that Lavoisier proved that "fixed air is a compound of carbon with the elastic fluid contained in the calx (of mercury)." He then established the identity of diamond with a variety of carbon as the former also when burnt in oxygen yielded the fixed air (carbon dioxide).

clude that this diminution was proportional to the increase in weight of the body burnt. He also proved that sulphur too when burnt far from losing gained in weight.

Lavoisier sums up his experiences of 1772 in these memorable words: "Not only sulphur and phosphorus but all bodies which gain in weight during combustion and calcination are to be brought under the same category; I am, indeed, inclined to believe that the augmentation in weight of metallic calxes is due to the same cause." Lavoisier now took up in right earnest the problem of the increase in weight of lead and tin during calcination. Nearly a century and a half before his time Jean Rey, as we have seen, had come to the conclusion that this "increase in weight was due to the fixation of air, which had become thickened and heavy by the vehemence and long continued heat of the fire." Robert Boyle, however, was of opinion —an opinion based upon the old notion of the *material* nature of fire—that the increase in weight was due to the absorption of the fire-particles, which penetrated through the pores of the glass vessel in which the metal was heated. Mayow, who was a contemporary of Boyle, had almost hit upon the true explanation; only he failed to isolate the particular constitutent of the air which took part in combustion.

The opinion of Boyle, however, prevailed at the time, nay, it was given currency to by the French chemist Lemery whose celebrated treatise, *Course of Chemistry*, was the recognised standard work all along. Lavoisier overthrew this erroneous notion by a simple experiment. He introduced a piece of tin in a closed vessel and weighed it carefully; it was then placed over a fire and strongly heated. On re-weighing the vessel it was proved that there was only a superficial coating due to the formation of the calx but no loss or gain in weight. He also collected the residual air and found that it had diminished in bulk and was rendered unfit for respiration. Lavoisier thus conclusively proved that the increase in weight of the metal was due to the fixation of *a portion of the atmospheric air.*

Matters stood thus up till the year 1774. Lavoisier was satisfied that the gain of the metal in weight was due to a portion of the air being fixed but as yet he had no clear conception as to the nature of its particular constituent, which took part in the formation of the calx; he racked his brains for its isolation but unfortunately the method he adopted proved treacherous.

From time immemorial charcoal had been used in all metallurgical operations for the extraction of the metal from the ores. We

all know that it is only a reduction of the oxide of the metal by carbon. The supporters of the phlogistic theory held that as charcoal *revived* the metal, it simply restored the phlogiston to the calx. In fact charcoal and all carbonaceous matter in general and later on inflammable air (hydrogen) were supposed to be very rich in this imaginary principle. Lavoisier heated a weighed quantity of the calx of lead (minium) and charcoal in a measured volume of air. He obtained the reduced metal and at the same time a volume of a gas which later on was identified as carbonic acid gas; it is this gas which Lavoisier at this stage in his career mistook for oxygen, *i.e.*, the elastic fluid which is fixed in the metal during calcination. It is easy to account for the error into which this great master-mind was led. The reaction of course, is as follows:

$$Pb_3O_4 + 2C = 3Pb + 2CO_2$$

Every tyro in chemistry now knows that carbon dioxide contains its own volume of oxygen but Lavoisier like his contemporaries had to grope in the dark. The solution of the vexed problem was at hand. Fortunately, there exists a metal which when heated in contact with air is converted into its calx, and the latter again, when more strongly heated, is reduced to the former metallic state. This peculiar property is shared by the red

precipitate or *mercurius precipitatus per se.* Eck de Sulzbach had already noticed this remarkable phenomenon in 1489 but he failed to draw any conclusion therefrom. Bayen, a fellow-student of Lavoisier (p. 92), heated a weighed quantity of mercury calx in a retort of known capacity communicating with a receiver of known volume inverted over water. The volume of gas evolved could thus be measured. This he did and also weighed the metallic mercury formed. He was startled with the result: here was a calx, which, when heated by itself *without the addition of charcoal* to provide the phlogiston necessary for reduction, not only yielded the metal but also a gas. Unfortunately, he did not examine the nature of the gas liberated nor did he even distinguish it from the fixed air obtained on reducing the calx with charcoal, though he noted that the volume of the gas evolved was in both cases approximately the same.* Bayen was thus on the eve of a great discovery, namely, of oxygen but he missed it by a hair's breadth. This experiment was conducted in April, 1774. On the 1st of August of the same year Priestley also repeated the same experiment, which we shall allow him to describe in his own words: "With this

* $2HgO = 2Hg + O_2$; $2HgO + C = 2Hg + CO_2$.
There would be as many molecules of oxygen liberated as those of carbon dioxide, hence the volumes would be the same.

apparatus, after a variety of other experiments, on the 1st of August 1774 I endeavoured to extract air from *mercurius calcinatus per se*, and I presently found that, by means of this lens, air was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water to it, and found that it was not imbibed by it. But what surprised me more than I can well express was, that a candle burned in this air with a remarkably vigorous flame. I was utterly at a loss how to account for it ...... but, however, being at Paris in the October following .... I frequently mentioned my surprise at the kind of air which I had got from this preparation to Mr. Lavoisier, Mr. Le Roy, and several other philosophers who honoured me with their notice in that city; and who, I daresay, cannot fail to recollect the circumstance. At the same time I had no suspicion that the air which I had got from the mercurius calcinatus was even wholesome, so far was I from knowing what it was that I had really found. In this ignorance of the real nature of this kind of air, I continued from this time (November) to the 1st of March following" (Fig. 3).

We have already seen that Lavoisier was on the look-out for the particular constituent which was responsible for the formation of the calx, but was as yet

unsuccessful in separating it from the air and thus proving its individual distinctive property. It was at this very psychological moment that Priestley, who happened to be accidentally at Paris as a companion of Lord Shelburne in his continental tour, in the course of his conversations with Lavoisier incidentally narrated his own experiences with regard to heating the red calx of mercury. The idea at once flashed across Lavoisier's mind that probably the long looked-for gas was at last in sight. He repeated the experiment and it led to most momentous and epoch-making results—the real explanation of the process of combustion; Lavoisier, in fact, not only isolated oxygen (vital air) but recognised it as a distinct constituent of atmospheric air and systematically explained the part it plays in combustion and respiration, and thus at one bound left Priestley far behind, as will be evident from the latter's recorded opinion in 1775 quoted above.* Henceforward, as Hartog tersely puts it, "Lavoisier acted as a sieve to separate the inaccurate work and conclusions of Priestley from the accurate."

I have devoted some considerable space

* The products of combustion of phosphorus, charcoal (carbon), sulphur, etc., were found to possess acid properties. Hence he gave the name 'oxygen' or 'generator of acids' to this new gas; but he overlooked the fact that when metals were burnt in oxygen the calxes (oxides) had the opposite, *i.e.*, *basic* properties.

to the discussion of the question: "Who discovered oxygen?" because the answer cannot be given in one word. It all hinges upon what is really meant by the term *discovery.* An eminent English chemist writing eighty years ago thus sums up his views: "Whoever may be called the discoverer of oxygen, whether Hooke and Mayow, who first inferred its existence in nitre and in air—or Boyle, who first *disengaged* the elastic gas from *minium*, or Hales, who *collected* it from the same material, or Nieuwentyt, who attributed its elasticity to the expansion of the fire particles lodged in the minium, supposing fire to be a particular fluid which maintains its own essence and figure, remaining always fire, though not always burning,—or Priestley, who observed that it supported combustion,—or Lavoisier who distinguished it as a gas, *sui generis*, and determined its principal combinations,—if the question be, which of these names deserves the highest place in the *history of this discovery*, a philosopher I apprehend might be apt to hesitate—especially perhaps between those which stand *first* in the list, and that which *stands last*" (Harcourt).

While the scientific world was slowly coming round Lavoisier's views Priestley could never shake himself free from the trammels of his preconceived notions and

always explained the phenomenon of combustion according to his phlogistic theory. Thus a candle when it burnt in air simply disengaged its phlogiston to the air, which (*i.e.* nitrogen), accordingly, was named 'phlogisticated air', whereas the same candle or a piece of charcoal burnt longer and more vividly in the "new species of air" (extracted from red calx)—being capable of taking more phlogiston from them it was called "dephlogisticated air". To quote Thorpe: "The discovery of oxygen was the deathblow to phlogiston. Here was the thing which had been groped for for years, and which many had even stumbled over in the searching, but had never grasped. Priestley indeed grasped it, but he failed to see the magnitude and true importance of what he had found. It was far otherwise with Lavoisier. He at once recognised in Priestley's new air the one fact needed to complete the overthrow of Stahl's doctrine; and now every stronghold of phlogistonism was in turn made to yield. Priestley, however, never surrendered, even when nearly every phlogistian but he had given up the fight or gone over to the enemy. When age compelled him to leave his laboratory he continued to serve the old cause in his study, and almost his last publication was the *Doctrine of Phlogiston Established.*"

In the history of scientific discoveries it is

often found that chance plays a great part but it should not be taken in the gambler's sense. As the great Pasteur once said: "In the fields of observation chance only favours the mind which is prepared;" in other words, the mind must be predisposed towards the reception of new truths, hence the property of the new gas which "under Priestley's observation led to nothing, in the hands of Lavoisier gave rise to one of the most important investigations in the annals of chemistry" (Harcourt). Priestley's frame of mind was just the reverse of that of Lavoisier as he often based his conclusions on random haphazard experiments. To quote his own words: "That more is owing to what we call *chance*, that is philosophically speaking, to the observation of *events arising from unknown causes*, than to any proper *design* or pre-conceived *theory* in this *business*." Eck de Sulzbach is probably the first chemist who in 1489 demonstrated experimentally that the metals increase in weight when calcined; what we now call metallic oxides are named by him fixed ashes of the metal. The *mercurius calcinatus per se* was prepared by him and called fixed mercury; he distinctly says that when the latter is subjected to distillation it disengages a spirit (invisible gas). He thus like Bayen narrowly missed being the discoverer of oxygen.

It now remains for us to conclude with the

considered opinions of some more English chemists who have bestowed much thought and study upon the subject. Says Rodwell: "Who is the discoverer? Is it the man who obtains a new body for the first time without recognising that it is different from anything else, or is it the man who demonstrates its true nature and properties, its inflammability? If the latter, assuredly Lavoisier discovered oxygen....................Priestley's observations read like the writings of the seventeenth century, Lavoisier's like those of the nineteenth. ....Not without reason, said M. Wurtz, 'La Chimie est une science francaise. Elle fut instituée par Lavoisier d'immortelle memoire'*. The petty jealousies which disfigured the history of science during the end of the last and commencement of the present century (19th) ought to find no place in our minds. The Republic of Science is large enough for everyman to receive his due." Mr. Pattison Muir reviewing this question observes: "To co-ordinate the facts of the science, to describe these facts accurately, to express them in a language which should make it easy to put together facts that were similar and to keep apart those which were unlike, and at the same time to overthrow the phlogistic theory; these were the tasks waiting to be accomplished

* Chemistry is a French science. It was founded by Lavoisier of immortal memory.

at the beginning of the last quarter of the eighteenth century. It is not often that the power of destroying and the power of reconstructing are united in so extraordinary a degree as they were united in Lavoisier, the greatest of all Chemists."

It will thus be seen that although some English chemists cannot forgive Lavoisier for what is according to them the appropriation of the credit which rightly belongs to Priestley, there are others, on the contrary, in whom the innate sense of justice and fair play so characteristic of the great nation finds full expression.†

The reader will find an interesting parallel in the controversy which raged with some degree of bitterness during the life-time of Newton and even after his death over the question of the priority of the invention of

† Thomson in his *History of Chemistry* takes Lavoisier severely to task for his omission of any mention of Priestley's name in connection with the discovery of oxygen, in the paper communicated to the Academy in 1775. He says: "I confess that this seems to me capable of no other explanation than a wish to claim for himself the discovery of oxygen gas, though he knew well that that discovery had been previously made by another." But Thomson seems to contradict himself and almost to give away his case when he says in another place: "It is not the man who forms the first vague notion of a thing that really adds to the stock of our knowledge, but he who demonstrates its truth and accurately determines its nature." Again, "It is obvious, however, that Lavoisier was on the way to make these discoveries, and had neither Scheele nor Priestley been fortunate enough to hit upon oxygen gas, it is exceedingly likely that he would himself have been able to make that discovery."

fluxions or infinitesimals. Leibnitz backed by eminent continental mathematicians claimed it as his own. On the other hand, Newton and his friends maintained with equal pertinacity that the German philosopher, while on a visit to England in 1673, had his hint from Collins to whom Newton had communicated the principles of the method.

Vice-Chancellor's Concluding Remarks.

Gentlemen,

We have listened with admiration to the brilliant series of lectures that Sir Prafulla has so very kindly given us. In the course of his lectures, especially on the points concerning the achievements of the ancient Hindus, he has displayed an admirable balance of judgment. As I listened to the lectures, I felt that Sir Prafulla has the splendid gift of distinguishing between real knowledge and counterfeit knowledge. One feels vanity in his countrymen and their achievements. Sir Prafulla has veneration for the achievements of his ancestors but he has none of that vanity which makes even the greatest of men blind to facts. He has shown us that he has got a greater love for truth than for national vanity. Gentlemen, in the course of his lectures Sir Prafulla has invited me to make comments on some points in my concluding remarks. I am afraid it will take a long time for me to deal with all those points and I do not want to tax your patience at this late hour. I can scarcely, however, resist the temptation of making a few observations on one of the most important and vexed questions in the History of Chemis-

try—the question whether Lavoisier tried to rob Priestley of the merit of the discovery of oxygen and the connected facts.

Priestley and Lavoisier were working by entirely different methods on the same subjects. Lavoisier had shown that if you calcine tin in a closed vessel, there is neither a gain nor a loss in weight, but that there would be an increase in weight on opening the vessel. Therefore he said:

Calx = Tin + Air.

On the 1st of August, 1774, Priestley isolated "dephlogisticated air." He found that the clax of mercury gave out an "air" on heating and it was not before March 1775 that he formed any idea of this gas. It was in that month that he gave a description of his classical experiment on burning in oxygen and concluded that calx was composed of "nitrous earth and phlogiston." In autum 1774, after he had made his first experiments he met Lavoisier in France and spoke to him about it. What he exactly told Lavoisier we do not know and he makes no accusations against the latter at that time. Lavoisier published his memoir on oxygen in the Easter of 1775, and later on refers to oxygen as "the gas that was discovered by myself, Priestley and Scheele." We have no record of the details of the conversation between Priestley and Lavoisier; and Priestley

made no accusations whatever during Lavoisier's life-time. Lavoisier died in 1794, and we find Priestley charging Lavoisier for the first time in 1800. This is rather strange and is sufficient to arouse suspicion in the mind of even the most casual reader. We also find Priestley accusing Ingenhouse of stealing his experiments on carbon dioxide about the same time. In this connection we cannot but take into consideration the complaints that Priestley used to make about the defects of his own memory.*

I have read all the memoirs in this connection. From what I have read of Lavoisier, I am all admiration for the character of this great man and I do not believe that he ever appropriated for himself any discovery that he himself did not make.

* That Priestley did not, like Lavoisier, keep regular records of his experiments as is done by ordinary laboratory students and when writing his papers had to draw upon memory—often a deceptive agent—is borne out by his own words: "I cannot, at this distance of time, recollect what it was that I had in view in making this experiment (of extracting 'air' from *mercurius calcinatus*)"—*On Dephlogisticated Air* (Alembic Club Reprints, No. 7. p. 15). As a proof of Lavoisier's unstinted admiration for the English chemists' discoveries of different kinds of 'air' may be cited the following. Speaking specially of Priestley he says: "Ce travil, dit Lavoisier en parlant des premiers travaux de Priestley, peut être regardé comme le plus pénible et le plus intéressant qui ait paru depuis M. Hales sur la fixation et le dégagement de l'air. Aucum des ouvrages modernes ne m'a paru plus propre à fair sentir combien la physique et la chimie offrent encore de nouvelles routes à parcourir"—Grimaux' *Lavoisier*.

A man who is going to plagiarise does not begin by praising the work of Boyle, Hales Black and specially of Priestley. Personally—I am of opinion,—and all the evidence that exists to-day leads me to it,—that Priestley has no reason to accuse Lavoisier of dishonesty in this respect.

Continuation of Footnote, p. 83.

"The Iron and Steel Institute held its annual meeting recently at Birmingham, when an interesting paper was read giving an account of the results of an examination of ancient iron specimens found at Richborough and Folkestone. It was stated that the iron had resisted corrosion to a far greater extent than would be the case with material made to-day. The ancient industry apparently possessed knowledge which was not shared by the present generation of manufacturers. Sir Robert Hadfield referred in this connection to an examination conducted at his works on iron from the famous pillar of Delhi which is reputed to be over 1,000 years old. He said that the analysis and tests to which the material had been subjected showed the iron to be a wonderful piece of work. It certainly had properties which enabled it to resist corrosion to a much greater extent than modern wrought iron. The piece which had been tested and of which photomicrographs had been taken was freer from 'inclusions' than any piece of iron that he had ever seen. He believed that it was the absence of 'inclusions' that enabled the metal to resist the tendency of most irons to corrode. It was a most remarkable fact that in spite of all the scientific advance which had been made in the metallurgical field the Pillar of Delhi was, as far as he could judge, a metal of much better quality than anything which could be produced to-day. He made that statement with a full sense of responsibility. Some of the secrets of metallurgy had died out."

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